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THE MORGAN SOIL TESTING SYSTEM

H. A. Lunt
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CONNECTICUT AGRICULTURAL EXPERIMENT STATION, NEW HAVEN, CONNECTICUT

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FOREWORD

The name M. F. Morgan is known to all workers in soil testing. Dr. Morgan not only was one of the earliest workers in this field but he was a pioneer in pushing back the frontiers of science on this phase of soils research. His "Universal Soil Testing System" is a monument to his researches.

In 1927 he started research on soil testing with the designing of a porcelain soil test block for determining soil reaction in the field by means of indicators. The second step was the development of a nitrate nitrogen test with diphenylamine, using the soil reaction test block. Then followed the addition of tests for ammonia, phosphorus, calcium, aluminum, chlorides, and sulfate, using separate extractants for each, and the introduction of the artist slab or spot plate. The original test block was retained for reaction tests but was enlarged to permit three tests to be made simultaneously.

In 1935 Dr. Morgan introduced the highly buffered "Universal" extracting solution, which permitted all of the principal tests to be conducted on portions of one extract, and substituted the filter funnel for the Morgan test block. At the same time the following tests were added: potassium, magnesium, manganese, iron, nitrite nitrogen and sodium. The pH meter was adopted for reaction tests in the laboratory but the soil test blocks were still used in the field.

By this time the Morgan System had become widely known and adopted in many other states and foreign countries. Subsequent development took the form of added tests - boron, zinc, copper, mercury, lead and arsenic.

Morgan's last soil test bulletin [1], Number 450, entitled "Chemical Soil Diagnosis by the Universal Soil Testing System" was unusually well received, and the supply of copies was soon exhausted. Because of the persistent demand for that bulletin, it has been deemed advisable to reprint it after incorporating certain revisions. Among the changes are the following: (a) rearrangement of the text, particularly the bringing together of directions for reagent preparation and test procedure; (b) incorporation of improved procedures, resulting from advances made in soil testing methods; (c) expansion of the section on plant tissue testing; (d) the omission of certain portions of the section on interpretation of soil tests; and (e) reduction of the number of color charts from six to four.

The tests herein described still comprise the Morgan Soil Testing System and it is to its founder, Dr. M. Francis Morgan, that this bulletin is dedicated.

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[1] Dr. Morgan lost his life on the Island of Leyte in the Philippine Islands January 15, 1945, while serving in the military forces.

The Morgan Soil Testing System

H. A. Lunt, C. L. W. Swanson, and H. G. M. Jacobson [1]

Soil testing offers a valuable contribution to the more intelligent management of the soil. The competent use of soil tests can help forestall crop failures due to inadequate or excessive fertilization and prevent wasteful use of unnecessary fertilizer ingredients. Soil tests can also be made during the growing season to check on the need for top or side dressings on certain crops, and thereby make possible increased yields.

The use of soil testing has spread rapidly and widely during the past 12 to 15 years, and its importance to agriculture has been firmly established.

However, the best fertilizer and liming practices cannot overcome the injurious effects of deficient or excessive moisture conditions, poor soil tilth, weed competition, improper cultural methods, deficiency of organic matter, or insect and plant disease troubles. All these factors must be reasonably favorable for plant growth, otherwise the most thoughtful care in providing suitable nutrient conditions will come to naught.

THE SOIL SAMPLE

Sampling

The interpretation of soil tests is based on the assumption that the sample actually tested is truly representative of the soil in the particular field or area sampled. Soils that are different in appearance, crop growth response, or past treatment should be sampled separately.

No simple rule for soil sampling will apply to all cases. Common sense is the best guide, bearing in mind that the final mixed portion actually subjected to test is only a spoonful from an area of land usually consisting of thousands of tons of soil. If the sample is not representative, the tests may lead to erroneous interpretation and unsound recommendations.

Soil Sampling Instructions

In cultivated fields and gardens, the soil is sampled by taking vertically cut shovel or trowel slices of uniform thickness, or borings, to a depth of 5 or 6 inches; in the case of permanent sod, such as pastures and lawns, the depth should be 2 or 3 inches. Each sample submitted for testing should be a composite of from 10 to 20 samplings well distributed over the field, garden or lawn. The number of places sampled depends on the size of the area and the uniformity of the soil.

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[1] Department of Soils. Grateful acknowledgment is made to T. R. Swanback of this Station's Tobacco Laboratory at Windsor for many helpful suggestions in the preparation of this bulletin, and to B. A. Brown, Arthur Hawkins, A. V. King and J. S. Owens of the University of Connecticut for reviewing the manuscript.

The soil from the various samplings should be mixed thoroughly and the larger stones and coarse roots removed. From a half pint to a pint of this mixture is sufficient to save for testing. If the soil is very wet, spread it out to air dry before mixing. It should *not* be dried in a heated oven. Ordinarily it is not advisable to sample when the soil is saturated with water, nor when it is extremely dry. Sampling tools must be free of lime, fertilizer, or other contaminent.

In fields or areas having more than one distinct soil type or important differences in past treatment or crop growth, a separate sample should be taken from each part. Likewise, portions of a field that show definitely poorer results than the average, where the cause is not readily explainable by obvious physical soil differences, should be sampled separately for comparison with samples from areas of normal production.

Separate samples from the subsoil may be desirable for the additional information they will provide. This would be helpful in the case of orchards, for example.

In fields where fertilizers have been applied in bands alongside the row, as in the case of potatoes and some vegetables, the sampling should be done between the rows or directly in the row between plants, avoiding the fertilizer band.

Preparation for Mailing

Pack the soil in a clean carton, box or bag not previously used for drugs, chemicals, fertilizer or other contaminating substances. Small candy boxes, ice cream cartons or coffee cans are satisfactory containers. Each sample should be marked by number, name of field, or other identifying legend, and should include the name and address of the person submitting the sample.

Soils are received for testing at the following laboratories in Connecticut:

Soils Department, Connecticut Agricultural Experiment Station, New Haven

Tobacco Laboratory, Connecticut Agricultural Experiment Station, Windsor

Agronomy Department, University of Connecticut, Storrs

Supplementary Information

Inasmuch as the cropping history and previous use of lime, fertilizer, or other materials influence the results obtained in the tests, and the use to which the land is to be put in the future has a bearing on the interpretation, the following information or as much of it as can be supplied should accompany the samples. When the samples are brought to the laboratory most of this information may be given orally:

1. Soil type name, if known.
2. Crop or crops to be grown.
3. Crops grown during each of the preceding 3 to 5 years.

4. Soil treatment with respect to lime, manure, fertilizer, etc., in each of the preceding 3 to 5 years.
5. Character of the land surface (whether hilly, rolling or level).
6. Drainage, either natural, or as improved by tile or ditches.
7. Underlying formation (whether "hardpan", sand, gravel or rock).
8. Special soil features, such as mellowness or hardness, tendency to erode, unusual shallowness of soil, stoniness, etc.
9. Approximate size of area represented by the sample.
10. Amount and kind of manure available for soil improvement.
11. Description of all unusual conditions, and abnormal results caused by known or unknown factors.

Time of Sampling

The soil is a dynamic body, teeming with micro-organisms whose activities vary from day to day and from season to season with changes in temperature, moisture and food supply. Nitrate and ammonia nitrogen contents of the soil are especially variable, as will be discussed in the section on test interpretation. A rapidly growing crop depletes soil of the nutrients required for plant growth. Thus, at the end of the growing season, soils show high tests for nitrates and potassium only when the amounts of these constituents added in the fertilizer, or becoming available in the soil, are in excess of crop demands. There are also seasonal fluctuations in soil acidity which influence the availability of plant nutrients to some extent. The degree of acidity is associated with the leaching of bases and production of nitrates. Acidity is normally at a minimum in early spring and at a maximum in midsummer.

All of the above factors must be taken into consideration in the interpretation of the tests. For general soil diagnosis, tests on samples taken in early spring are most reliable. Soils studied during the growing season give tests closely related to the performance of the crop, and are particularly valuable in determining immediate need for supplemental fertilization. Tests in the autumn after the crop is harvested best indicate whether or not the fertilizer has been in excess of crop needs. Fall testing has the added advantage of allowing ample time in which to obtain materials and lay plans for spring work. The choice of time when the sample is to be taken depends, therefore, upon the purpose for which the test is made.

Preparing the Soil Sample for Testing

The field-collected sample, upon receipt for testing, is usually more or less moist. If too sticky to be screened, it should be dried to a mellowmoist condition. It is *never dried* in a heated oven. After mixing the entire sample, a portion of suitable size (usually about 100 ml) should be screened through a 2 mm or 10-mesh sieve to remove stones, gravel or coarse roots, and then mixed. The screened sample, if moist, should either be tested promptly (within 12 hours or so), or placed in a refrigerator or spread out to dry for later testing. Although the first

procedure is preferable, it is more convenient from a practical standpoint in making many determinations in the laboratory to allow all samples to become air-dry before testing, thus placing them all on a comparable basis. If held for some time, they should be kept away from laboratory fumes, particularly ammonia or acid vapors.

SOIL TEXTURE

Soil texture, involving the relative proportion of sand, silt and clay in the soil, is an important consideration in the proper interpretation of soil quick tests. A definite measure of soil texture is obtained by mechanical analysis. A useful method, giving satisfactory practical results on most soils, is the hydrometer technique devised by Bouyoucos (3, 4). However, it is usually impractical to make such measurements on the large numbers of soil samples usually involved in quick test operations. As a rule, the texture of the soil can be fairly well assessed by a skilled observer, chiefly on the basis of the feel of a moderately moist soil when rubbed between the thumb and forefinger. A few simple rules are helpful in this connection for characterizing soils of the more common textural classes.

Loamy sand: harsh, gritty feel; very slight tendency of the moist soil to stick together when pressed.

Sandy loam: definitely gritty; when moist the soil may be pressed into a soft mass, and when moistened to its maximum sticky point it is not perceptibly sticky.

Fine sandy loam: mellow and only moderately gritty feel; when moist, the soil may be pressed into a firm mass. At its maximum sticky point it is very slightly sticky.

Loam: mellow, moderately smooth feel; moist soil may be rolled into firm rods; slightly sticky.

Silt loam: smooth and "floury" feel; moist soil rather sticky; readily rolled into firm, slender rods.

Clay loam: very smooth "slippery" feel; definitely sticky when moist; easily modeled into any shape.

A more detailed description of soil textures has been published by the Soil Survey Division of the United States Department of Agriculture [1].

ESTIMATION OF SOIL ORGANIC MATTER CONTENT

Some evaluation of the organic matter content of a soil is also essential to the proper interpretation of soil tests. A number of soil testing laboratories make some measurements of organic matter as a supplement to the quick test procedure. A reliable, reasonably rapid technique is the Tiurin (46) modification of the Schollenberger (39) di-

[1] Committee Report on Soil Texture. Soil Survey Division, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. 1949. Mimeographed.

chromate method, also outlined by Merkle (26). Thomas and Williams (44) employ a modified adaptation of the Schollenberger method, involving only partial decomposition of all of the organic matter.

A useful soil measurement is loss-on-ignition, determined by igniting the previously oven-dried soil at dull red heat to constant weight. However, it gives values of much higher magnitude than can be ascribed to the organic matter content, particularly on loamy or clay soils relatively low in humus, due to the volatilization of chemically combined water and certain inorganic elements. Such a procedure is most satisfactory when soils of similar textural type are being compared.

Persons who are familiar with the color of the soil at various organic levels can usually make a fair estimate of organic matter by observation. It must be borne in mind that the dark color imparted to the soil by humus is deepened by moisture; also, that a sandy soil is much darker at the same organic content than a heavier soil. Under Connecticut conditions, the colors of moderately dry soils, at varying organic levels, are approximately as follows:

TABLE 1. APPROXIMATE ORGANIC MATTER CONTENT OF SOILS IN CONNECTICUT AS INDICATED BY COLOR

	Soil Texture				
	Loamy sand	Sandy loam	Fine sandy loam	Loam or silt loam	Clay loam
Soil Color [1]	% OM	% OM	% OM	% OM	% OM
Brownish yellow, reddish yellow, or light gray	<0.5	<0.7	<1.0	<1.2	<1.5
Light yellowish brown, light reddish brown, or light brownish gray	0.5-1.0	0.7-1.5	1.0-2.0	1.2-2.5	1.5-3.0
Grayish brown, brown or yellowish brown	1.0-2.5	1.5-3.0	2.0-4.0	2.5-5.0	3.0-6.0
Dark brown, dark reddish brown or dark grayish brown	2.5-4.0	3.0-5.0	4.0-6.0	5.0-7.0	6.0-8.0
Very dark brown, dark reddish gray, or black	>4.0	>5.0	>6.0	>7.0	>8.0

[1] Color names taken from Committee Report on Soil Color. Soil Survey Division, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. 1948. Mimeographed.

In prairie regions, soils are usually darker at the organic matter content indicated in the above scheme.

SOIL REACTION (pH) TESTS

Soil reaction, in terms of the pH scale, is one of the most important single factors involved in the chemical fertility of soils. Knowledge of the degree of acidity or alkalinity is almost essential to the proper interpretation of the results of the other chemical tests, especially those for phosphorus, calcium, magnesium, aluminum and manganese. The pH test is necessarily a separate measurement from the tests that are applied to the soil extract in the Morgan Soil Testing System.

Most laboratories and soil testing centers use a pH meter for determining soil reaction. Reliable instruments are on the market, most of which are of the glass electrode type. The research laboratory sets operating on dry cells are the most accurate, but the recently developed AC line-operated pH meters are easier and faster to manipulate, are free of battery worries, and are sufficiently accurate for routine soil testing.

The quinhydrone electrode type of instrument is sometimes used with good results but it is subject to considerable error on certain soils, particularly those containing oxidizing substances such as manganese dioxide.

Procedure With Glass Electrode pH Meter

Into a small beaker (50 or 100 ml) place enough soil to make it about one-third full, then add distilled water, while stirring, until the mixture attains the consistency of a thin paste or thick soup. Immerse the electrodes and take the reading. Soils high in organic matter, particularly peats, should be allowed to soak with occasional stirring for half an hour or more before taking the reading.

Soils that have been allowed to air dry tend to show a slightly higher acidity (lower pH value) but the difference is usually less than 0.2 pH, which can ordinarily be ignored.

Colorimetric Method for pH

When testing is not conducted on a sufficient scale to justify the purchase of a pH meter, the measurement of soil reaction may be done colorimetrically by the use of indicator dyes.

Reasonably accurate results can be obtained with narrow-range dyes, provided the proper dye is chosen for the sample being tested. Generally with unknowns the test is facilitated by using three dyes simultaneously, with the expectation that one of them will encompass the pH of the sample.

For approximations where an accuracy of 0.5 pH is sufficient, one can use a dye with a wider range, say from pH 4 to 8. Full range indicators, pH 1 to 14, are of no value in soil testing work.

Determining pH with Single Dyes

Indicators: Bromcresol green, chlorphenol red, and bromthymol blue prepared separately, each at a concentration of 0.04%. The total range

covered by these three indicators is from pH 3.8 to 7.6. For extremely acid soils, pH 3.0 - 4.6, use bromphenol blue 0.04%; and in regions of neutral to alkaline soils, use cresol red (pH 7.2 - 8.8) and thymol blue (pH 8.0 - 9.6), both at 0.04% concentration.

Procedure: Place about ½ teaspoonful of soil in a small test tube (½" x 4" is a convenient size), add a small quantity of barium sulfate[1], 4 ml of distilled water and 3 drops of indicator. Stir vigorously with a glass rod, and allow to settle. (Stirring is more satisfactory than shaking). Compare the color of the supernatant liquid with a color chart or with the colors described in Table 2.

Determining pH with Wide-Range Dyes

Indicator: Equal quantities (0.025 g) of bromcresol green, bromcresol purple, and cresol red are ground together in a mortar with about 1.5 ml of normal NaOH solution and ½ ml of distilled water, then diluted to 100 ml with distilled water (37). Alternatively, one may use a commercial indicator which has approximately the same range.

Procedure: Identical to that described for single dyes. The colors obtained are as follows[2]:

Acidity	*pH*	*Color*
Very strongly acid	4.0	Wax yellow
Strongly acid	4.5	Light greenish yellow
Acid	5.0	Light olive green or dark yellow green
Moderately acid	5.5	Grass green or very dark yellow green
Slightly acid	6.0	Pistachio green (a grayish green)
Very slightly acid	6.5	Delft blue (a grayish blue)
Neutral	7.0	Light bluish violet
Alkaline	8.0	Mulberry purple

DETAILED DESCRIPTION OF THE MORGAN SOIL TESTING SYSTEM

Since the publication of Bulletin 450 (34), Peech and English (36) have made rather extensive studies on the use of the methods herein described. In an effort to increase the accuracy of the results, they introduced a number of refinements for some of the tests and made some substitutions in the case of others.

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[1] Use only neutral x-ray purity grade. Ordinary C. P. grade is likely to be acid. Make a pencil or ink line on the flat end of a wooden toothpick ⅜" from the end. Using the toothpick as a spatula, all that it will hold up to the line constitutes one measure. Use one or two measures for each sample of soil. The only purpose of the barium sulfate is to hasten the clarification of the suspension. If omitted, it is necessary to wait from one to eight hours for the suspension to clarify.

[2] Color names are taken from Ridgeway's "Color Standard and Color Nomenclature". A. Hoen and Company, Baltimore, Md. 1912.

TABLE 2. APPROXIMATE COLOR RANGES FOR pH INDICATORS USEFUL IN SOILS WORK

pH	Brom-phenol blue	Brom-cresol green	Chlor-phenol red	Brom-thymol blue	Cresol red
3.0	yellow	.....	.....	.....	.....
3.4	↓	.....	.....	.....	.....
	grading				
3.8	↓	yellow	.....	.....	.....
4.2	to ↓	greenish yellow	.....	.....	.....
4.6	lavender violet	green	.....	.....	.....
5.0	.....	blue green	yellowish orange	.....	.....
5.4	.....	blue	orange	.....	.....
5.8	.....	.....	reddish salmon	yellow	.....
6.2	.....	.....	salmon pink	greenish yellow	.....
6.6	.....	.....	rose	yellowish green	.....
7.0	.....	.....	.....	green	.....
7.4	.....	.....	.....	greenish blue	orange yellow
7.8	.....	.....	.....	blue	salmon
8.2	.....	.....	.....	.....	yellowish red
8.6	.....	.....	.....	.....	reddish purple
9.0	.....	.....	.....	.....	purple

The value of their work is fully recognized, and for certain purposes where a greater degree of accuracy is required and time taken to make the tests is of secondary importance, their proposed changes should be incorporated in the procedure. However, for routine soil testing where speed is essential and labor and laboratory space are limited, the tests described in the present bulletin are believed adequate for the purposes for which they are intended. It should be remembered that the procedures described in this bulletin are primarily *quick* tests.

The Morgan Soil Extracting Solution

A distinctive feature of the soil testing methods herein described is the employment of a single extracting solution that permits the development of specific tests for determining the nutrient status of the soil.

The extracting solution is a 10% solution of sodium acetate (0.73N) in 3% acetic acid (0.52N), and has a pH of 4.8. This provides a weakly ionized organic acid buffered with its sodium salt [1]. It is suitable for the usual routine tests and for most others with the exception of sodium and chlorine. These require separate extractions with appropriate solutions.

All chemicals used for making the tests described in this bulletin should be of C.P. or A.R. grade or of a special type as noted.

Preparation of the Extracting Solution

Add 100 g of sodium acetate ($NaC_2H_3O_2.3H_2O$) to 500 ml of distilled water. After this is dissolved, add 30 ml of glacial acetic acid and make up to 1 liter.

General Plan

The filtered extract obtained from soil treated with the Morgan soil extracting solution or other extractant is tested for various constituents by transferring small quantities, usually from 1 to 10 drops, to either a porcelain or glass spot plate, or to small glass vials of uniform size (10 mm by 60 mm), to which is added the appropriate reagents for the development of the color or turbidity tests in question. The general plan of these tests follows for the most part the technique for microchemical tests extensively developed by Feigl (14, 15, 16). Application of such procedures in quick chemical soil testing was first reported by Morgan in connection with the nitrate test (30).

Chemical tests of this type must be conducted with reagents that are sensitive to approximately the same concentration of any given constituent likely to be present in the soil extract, without interference by any other ions that may be present. Where such interference does occur by giving a similar test or by increasing or decreasing the sensitivity of the test, the extract must be purified by some chemical technique designed to remove or inactivate the disturbing substance. This may be accomplished in a refined laboratory method, but it is not ordinarily practicable in quick test procedures.

Equipment

The following list itemizes the equipment normally required for conducting the usual routine tests. Specifications are those that have been found most generally desirable, and the tests are calibrated on the basis of their use. A sufficient quantity of glassware, etc., is provided for testing 12 soil samples at the same time [2]. For larger operations, the numbers may be increased.

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[1] Additional reasons for selection of this type of extracting solution are given in Bulletin 450 (34).

[2] Assembled sets of the above equipment and commercially prepared extracting solutions and reagents may be obtained from the LaMotte Chemical Products Company, Baltimore, Md., for those who desire this service.

1 Supply bottle, 10 liters or larger capacity, for soil extracting solution.
1 Cylinder, or burette, graduated to hold or deliver in 10 ml units.
1 Spoon, measuring, teaspoon size.
1 Block, wooden, or a rack with 12 holes of ¾ inch diameter, for supporting filtering tubes.
2 Blocks, wooden, or metal rack, with 12 holes of ½ inch diameter, for supporting test vials.
Filter paper, 9 cm diameter, C. S. and S.597, Munktell No. 0 or similar grade.
12 Tubes, soil filtering, 15 mm inside diameter, with funnel mouth 35 mm diameter and air vent (or separate tubes and funnels of similar dimensions).
12 Medicine droppers [1], with unflattened straight tip of 2 mm diameter, or transfer pipettes graduated to 0.05 ml. [2]
12 Rods, glass, 4 mm by 100 mm. [3]
24 Vials [1], glass, 60 mm long, 10 mm inside diameter.
6 Spot plates, white porcelain, containing 12 depressions of 20 mm diameter and 7.5 mm depth (approximately 20 drops capacity).
1 Spot plate, clear glass, with 9 or 12 depressions.
9 Bottles, 1 oz., with dropper pipette in screw cap, for test reagents.
3 Bottles, 2 oz., with dropper pipette in screw cap, for test reagents.
1 Bottle, glass dropping stopper, 1 oz., for nitrate reagent.

The Soil Extraction

The procedure that has been used with success on the sandy loam and loam soils of Connecticut involves direct extraction of the soil with the extracting solution. The soil mass is placed in a folded filter paper cone and a measured amount of the extracting solution added to the soil, percolating through it. This technique works best on soils that are readily moistened throughout upon the addition of the first 2 or 3 ml of the extracting solution, so that the remainder of the liquid percolates readily through the entire soil mass. Other investigators using the Morgan or similar types of soil extractants have adopted other procedures of extraction. While not as simple and rapid as the technique described above, they may be used to advantage on soils that are less readily saturated with the extractant, or those with heavier textures. Hence, alternate procedures of extraction are included.

Simple Percolation Extraction

Fit a folded filter paper of 9 cm diameter into the funnel of the soil filtering tube (or an ordinary glass funnel); place a level teaspoonful of the soil sample inside the filter cone, and press down gently with

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[1] Medicine droppers should be carefully selected for uniformity of drop size, and vials for uniform inside diameter.

[2] Automatic pipettes which can be calibrated to deliver small quantities of solution are obtainable in some supply houses.

[3] In place of stirring rods, one can use a glass tube of small bore, with one end tapered and curved. Stirring is accomplished by blowing through the tube.

the back of the spoon[1]. Measure out a 10 ml portion of the Morgan extracting solution, and pour slowly over the soil mass in the filter. If the soil does not readily absorb the liquid, the extraction procedure should be repeated in another filter tube after first moistening the soil slightly with distilled water. Permit the filtration to proceed to completion. If the volume of leachate obtained is appreciably less than average, add more extracting solution to equalize the volume. In removing the filter cone of soil, squeeze it gently to extract any remaining liquid which may have collected at its top. Remove the funnel and insert a clean medicine dropper into the filtrate vessel. Pump the liquid up and down the medicine dropper 2 or 3 times to insure thorough mixing of the soil extract. Each filtrate vessel should be supplied with an individual dropper for transferring portions to the spot plates for the various tests.

Alternate Extraction I

Place a teaspoonful of soil, gently packed and leveled, into a 50 ml beaker. Add 10 ml of the Morgan soil extracting solution. Stir vigorously for 1 minute and filter through a paper of quality indicated above into a 20 by 75 mm glass vial or other suitable container. Remove the funnel and insert a clean eyedropper pipette into the filtrate vessel. Proceed as directed above.

Goss and Owens (18) recommend placing the soil and extracting solution in a 50 ml Erlenmeyer flask and shaking with an automatic shaking machine for 15 minutes before filtration. Results by such a procedure are somewhat higher, for some constituents, than by the shorter time of extraction. However, data on check soils by various methods do not show any consistent improvement in correlation for the more exhaustive extraction.

Alternate Extraction II

Place a rubber policeman over the end of the stem of a 50 mm filter funnel provided with an 18 mm disc of fritted glass (porosity-1). Add 10 ml of the extracting solution and a level teaspoonful of the soil sample. After 15 minutes, remove the policeman, permitting the extract to drain into the collecting flask or tube. This general procedure has also been used by Thomas and Williams (44) and by Miles (28). Results have not been studied in detail in comparison with the simple percolation extraction, but they are believed to be similar to those obtained by the Goss and Owens modification.

It is likely that no one method of extraction will be uniformly applicable to all types of soil. It is suggested that each of the procedures be studied on numerous soil representatives of the locality involved, before selecting the one that appears to be the most desirable.

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[1] The New Jersey Agricultural Experiment Station places the soil first in a small paper cup, adding one-quarter teaspoon of Darco carbon, grade No. 60, then adding Morgan's extracting solution, stirring the mixture for 1 minute, and then pouring it on the filter paper. Use of the carbon produces clear soil extracts, especially in soils high in organic matter. Private communication from A. L. Prince.

Lighting Conditions in Conducting the Tests

It is possible to make reasonably close comparisons of color and turbidity reactions developed in the various quick tests under good natural light. A north or northeast window is preferable, since the reflections obtained in direct sunlight make matchings difficult. However, natural lighting is unsatisfactory on dark, cloudy days and in late afternoons in the winter season; hence, artificial illumination by a good fluorescent lamp equipped with daylight bulbs is desirable. The value of attention to lighting and other details in soil testing techniques has been discussed by Constable and Miles (8).

Special Precautions

All glassware, spot plates, stirring rods, etc., should be washed with clean tap water and rinsed with distilled water immediately after being used. The spot plates require occasional cleaning with a sulfuric acid-dichromate cleaning solution to remove stains.

The medicine droppers may be washed by vigorously pumping water in and out of them by intermittent pressure on their bulbs. Any adhering precipitates should be carefully brushed loose from the bottoms of the test vials before using for testing work.

Reagent bottles should be kept clean, and encrustations should not be permitted to accumulate around their caps.

Vials, droppers, pipettes [1] and other measuring equipment used should be standardized to insure that the same amount of reagent is added each time. Technique of using such equipment should also be standardized to obtain best results.

Any reagent that fails to give a satisfactory blank test with the soil extracting solution, or that fails to give correct tests with solution standards or on "standard" soils should be rejected. It is advisable to check reagents by testing the solutions with a standard solution every three or four days.

TESTS MOST COMMONLY USED IN ROUTINE TESTING

Nitrate Nitrogen

The diphenylamine test originally used for nitrates has been replaced by the brucine method because of the greater dependability of the latter. Both methods, however, are described.

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[1] The University of New Hampshire Agricultural Experiment Station uses a 1 ml Mohr pipette for measuring the soil extract, graduated in 1/100, as follows:

Nitrate nitrogen	0.05 ml
Ammonia nitrogen	.2 ml
Aluminum	.1 ml
Phosphorus, magnesium, potassium, and calcium	.5 ml

Private communication from G. P. Percival.

Brucine Method [1]

Reagent A: Dissolve 1 g of brucine in 25 ml of chloroform. Store in a tightly stoppered amber glass dropping bottle, and while in use keep one finger over the mouth of the bottle to prevent evaporation.

Reagent B: Sulfuric acid, concentrated (sp. gr. 1.84).

Procedure: To 3 drops of soil extract in a spot plate (or glass vial) add 2 drops of brucine solution and 7 drops of sulfuric acid. Mix well. Readings may be taken at once (or within a few seconds), or after 12 to 15 minutes. In the first case the colors for low to very high readings range from a pale gray or pinkish gray to a salmon red; in the second case from light gray to bright yellow. A color chart for the latter is contained in the Appendix. In the case of very high readings the test should be repeated on a diluted extract. (To one drop of extract add 9 drops of extracting solution, mix and test as above. The reading obtained should be multiplied by 10).

Diphenylamine Method [2]

Nitrate nitrogen reagent: Dissolve 0.05 g of diphenylamine in 25 ml of concentrated sulfuric acid at a temperature not to exceed 24°C. Store in a clear glass-stoppered dropping bottle protected from bright light. The resulting solution should have no trace of bluish color, and should give a colorless "spot" when 4 drops are added to 1 drop of distilled water. This test should be made frequently since continued exposure to light and accidental contamination may require the preparation of a fresh reagent. The solution is very corrosive, and should not be allowed to come into contact with rubber. Care should also be taken to prevent injury to hands or clothing.

Testing Procedure: Transfer 1 drop of soil extract to the spot plate. Add 4 drops of the reagent; let stand for 2 minutes; stir and compare the intensity of the resultant blue color with the color chart.

Stirring immediately after adding the reagent is not recommended, since the blue color develops most rapidly in the film of contact between the reagent and the extract. Somewhat deeper colors result from prolonged standing in excess of 2 minutes, but for convenience of operation, the charts are standardized on the basis of this time.

If a very deep blue color is obtained, the test should be repeated on a diluted solution as described for the brucine test.

If the first drop of the reagent produces an immediate blue color, the presence of nitrogen as the nitrite is suggested, and a test for nitrite is desirable.

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[1] Adapted from the method proposed by Peech and English (36).

[2] Adapted from the method originally proposed by Morgan (30).

Ammonia Nitrogen

Nessler's reagent: Dissolve 5 g of potassium iodide in 15 ml of distilled water. Add a saturated solution of mercuric chloride until a slight precipitation occurs. Add 40 ml of a 50% solution of potassium hydroxide. Dilute to 100 ml, allow to settle for one week, decant and keep in a brown glass bottle. Two drops of this reagent, added to 4 drops of the Morgan leaching solution, should give a practically colorless spot. Nessler's reagent prepared according to other reliable laboratory formulae may also be employed.

Testing Procedure: Transfer 4 drops of the soil extract to the spot plate. Add 2 drops of the reagent. Let stand 1 minute; then stir and compare the resultant yellow to orange color with the color chart in the Appendix.

Phosphorus

Reagent A: Dissolve 12.5 g of sodium molybdate, by gentle heating, in 100 ml of distilled water. Mix 50 ml of glacial acetic acid and 350 ml of distilled water in a 600 ml beaker. Add the above solution of sodium molybdate slowly with constant stirring to the acetic acid solution. Store in a brown glass bottle.

This reagent should not show more than a trace of sediment in the bottle in which it is stored. If the molybdate has a definite tendency to precipitate, the reagent is unreliable. When properly prepared, this reagent should be stable for 6 months or more; but unless the directions are carefully followed, it may deteriorate in a much shorter time.

Reagent B: Stannous oxalate solution. *This should be prepared fresh on the day of use.* On the flat end of an ordinary wooden toothpick make a pencil or ink mark $\frac{1}{8}$ to $\frac{3}{16}$ inch from the end. All of the stannous oxalate the toothpick will hold up to that mark is added to 10 ml of Morgan's extracting solution. Mix well, making sure all is dissolved before using.

Testing Procedure: Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of reagent A and 2 drops of reagent B (the latter freshly prepared on the day of use). Stir, let stand for 1 minute and compare the intensity of blue color with the color chart in the Appendix.

If more than 1 drop of reagent A is added, the test is abnormally high. If more than 2 drops of reagent B are used, or if that reagent contains more than the designated amount of stannous oxalate, a "dirty" blue or greenish blue color results.

The test should be read in 1 minute since, with a longer period of standing, the soil extracting solution when tested as a blank develops a definite blue color. Also, upon standing for a longer time, the blue color tends to develop a hue not readily matched with the chart.

Occasionally soils from golf greens and soils that have been treated with mercury compounds yield a grayish to black precipitate upon the

addition of reagent B. This is due to reduction to metallic mercury by the stannous compound in this reagent. In such a case, the phosphorus cannot be reliably measured.

Soils that have been treated with heavy amounts of arsenic compounds for insect grub or earthworm control may give abnormally high phosphorus tests. However, moderate treatments and arsenical spray residues rarely affect the test by the procedure described above.

More exact readings of very high tests may be obtained by diluting 2 drops of extract with 8 drops of extracting solution.

Potassium [1]

Reagent A: Dissolve 5 g of cobalt nitrate ($Co(NO_3)_2.6H_2O$) in 47.5 ml of distilled water and 2.5 ml of glacial acetic acid. Store in a brown bottle. Dissolve 30 g of sodium nitrite ($NaNO_2$) in distilled water and dilute to 50 ml with same. Store in a brown bottle. Mix these two solutions in equal parts at least 24 hours before using, in quantities sufficient to last one or two weeks. Cover the container loosely overnight to allow escape of the poisonous nitric oxide fumes. Filter if necessary and store in a brown, glass-stoppered bottle. This final solution, sodium-cobaltinitrate, may deteriorate after a few weeks if not stored in a refrigerator. The danger of deterioration can be avoided by mixing only enough of the final solution to last a short time.

Reagent B: Mix 90 ml of iso-propyl alcohol with 10 ml of neutral formaldehyde. Store in a bottle with a tightly fitting screw cap.

Testing Procedure: Transfer 10 drops of the soil extract to the test vial (10 mm inside diameter). Add 1 drop of reagent A and 12 drops of reagent B. Let stand 1 minute; shake the vial gently and let stand 2 minutes longer. Estimate the resulting amount of yellow precipitate by the following use of the "line" chart:

> Hold the vial in a vertical position directly over the lines on the chart, with the bottom of the vial ¼ inch above them. Look down through the vial at the different groups of lines, until the set is found which can be *barely perceived.* The test is read which corresponds to this set of lines.

The printed "line" chart does not permit precise differentiation at the lowest tests. If but the faintest perceptible turbidity is to be observed, the estimate should be "very low". If the liquid remains clear and limpid, the estimate should be "trace".

If the test is very much beyond the visibility of the deepest lines on the chart, a preliminary dilution of the extract with the extracting solution may be made, although the results are apt to be less reliable than in the case of most of the other tests. It is necessary to mix fully the diluted liquid before testing.

Chart for Potassium (and Sodium): Additional charts for potassium (and sodium) may be prepared with India ink as described below.

[1] For procedures using a flame photometer, see Stanford, G., and English, L. Use of the flame photometer in rapid soil tests for K and Ca. Agron. Jour. 41: 446-447. 1949.

Relative Test Index	
10	India ink full strength; wide line (about 1/32")
8	India ink 2 parts; water 1 part.
6	India ink 1 part; water 4 parts.
4	India ink 1 part; water 12 parts.
2	India ink 1 part; water 16 parts.
1	Hard pencil (no. 4).

Lines for index 2 to 8 may be made about half the width of those for index 10.

Calcium

Reagent: Mix 10 g of sodium oxalate with 100 ml of distilled water. Let stand for 24 hours, and decant the clear supernatant solution to the reagent bottle for use as required.

Procedure[1]*:* Transfer 10 drops of the soil extract to the test vial. Add 1 drop of the reagent, shake vigorously and let stand for 5 minutes. Estimate the resultant white turbidity by means of the "line" chart, as described for potassium.

Magnesium

Reagent A[2]*:* Dissolve 0.02 g of Thiazol yellow (General Aniline Works, Rensselaer, N. Y.) in 100 ml of distilled water. Store in an amber glass bottle.

Reagent B: Dissolve 15 g of sodium hydroxide in 100 ml of distilled water. This is used also as manganese reagent B.

Procedure[3]*:* Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of reagent A and 3 drops of reagent B. Stir, let stand 1 minute and compare the resultant light salmon to deep red color with the chart.

The magnesium test is somewhat affected by aluminum in amounts sufficient to give high or very high tests. Under such conditions, the magnesium test is somewhat lower than it should be. Due allowance should be made for this factor in interpreting the tests.

Soils of high active calcium content give extracts that tend to coagulate the magnesium color, making test readings difficult and unreliable. This may be overcome in most cases by adding 4 drops of a 50% glycerin solution prior to adding reagent A. The liquid in the test cup should be stirred thoroughly with a glass rod before adding reagent B.

Aluminum

Reagent: Place 0.05 g of hematein (Eastman Kodak Company) in a 30 ml beaker. Add 5 ml of ethyl alcohol (95%). Triturate with a rub-

[1] Adapted from the procedure proposed by Morgan (31).
[2] Adapted from Mikkelson and Toth (27).
[3] Adapted from the method of Spurway (43) in the use of reagent A.

ber tipped stirring rod and decant clear solution to the storage bottle. Triturate with successive 5 ml portions of alcohol and decant, until all of the hematein is dissolved. Make up to a volume of 100 ml with the ethyl alcohol. (This should be freshly prepared every two months, and should be stored in a refrigerator if possible).

Aluminum stain remover: Mix 25 ml of concentrated hydrochloric acid and 25 ml of distilled water. (Same as iron reagent A).

Testing Procedure[1]*:* Transfer 2 drops of the soil extract to the spot plate. Add 2 drops of the Morgan soil extracting solution and 1 drop of the reagent. Let stand 1 minute, and compare the resultant color with the chart in the Appendix.

If a "dirty" blue-gray color results from this test, it is indicative of abnormal concentrations of active iron, and a test for this constituent is desirable.

After completing the reading, add 1 drop of the aluminum stain remover (1:1 HCl) and shake the block gently before washing it. This prevents the formation of a stain on the porcelain which interferes with subsequent tests.

Manganese

Reagent A: Dissolve 0.1 g of benzidine in 20 ml of glacial acetic acid. Dilute to 200 ml and filter.

Reagent B: Sodium hydroxide solution (See magnesium reagent B).

Reagent C: A saturated solution of potassium periodate in the Morgan extracting solution.

Reagent D: Manganese reagent for supplemental test consisting of a saturated solution of tetra-base (Eastman Kodak Company) in ethyl alcohol (95%).

Testing Procedure[2]*:* Transfer 10 drops of the soil extract to the spot plate. Add 2 drops of reagent A, stir and add 1 drop of reagent B. Stir and compare the resultant blue color with the chart as quickly as possible, since the intensity of color fades rapidly after a few seconds.

If more than 1 drop of reagent B is added, or if the tip of the pipette used in transferring that reagent is abnormally large, the test may fail, since too much alkalinity interferes with the test.

If the soil contains abnormal concentrations of nitrite nitrogen, a brownish yellow discoloration is to be noted in the routine manganese test.

If no perceptible blue color is detected, add 2 drops of reagent C. Stir at once with a glass rod and let stand for 2 minutes. If not more

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[1] Adapted from the use of logwood extract in the testing for aluminum by Colwell and Parker (7).

[2] Adapted from the spot plate test of Feigl (12).

than a faint blue color appears, the test is recorded as "negative", and the soil contains less than 2 pounds of manganese per acre. If there is a strong blue color, without a trace of green or yellow, a "trace" amount is read, representing approximately 2 pounds per acre. If the color is green, gradually changing to yellow, this is recognized as "trace plus", or approximately 3 pounds per acre. If any blue color was apparent in the previous stage of testing, a deep yellow to orange-yellow color develops almost at once.

The above additional procedure is especially useful in differentiating soils suspected of being manganese-deficient.

The following alternate procedure may also be used to advantage when little or no reaction is obtained from the above method: Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of reagent C and 1 drop of reagent D (tetra-base solution). A deep blue color develops almost at once in soils usually rated as "very low" or better by the regular method. When the resultant color is only faintly blue, the test may be considered as "negative". With experience, an operator can readily distinguish differences between tests even with the traces of extractable manganese that usually typify manganese-deficient soils. It should also be noted that traces of the violet permanganate color can be observed upon the addition of reagent C alone, after 2 or 3 minutes, when the extract contains a considerable amount of manganese.

SPECIAL CHEMICAL TESTS

One or more of the following tests may be of definite diagnostic value under conditions that seem to warrant them or when the abnormal conditions of the soil are not evidently correlated with the routine tests.

Iron

Reagent A: Dilute hydrochloric acid of ordinary C.P. concentration (approximately 38% HCl) with an equal volume of distilled water.

Reagent B: Dissolve 10 g of potassium ferrocyanide and 0.1 g of potassium ferricyanide in 100 ml of distilled water.

Reagent C: Dissolve 15 g of potassium sulphocyanate in 100 ml of distilled water.

Reagent D: Dissolve 0.2 g of potassium ferricyanide in 100 ml of distilled water.

Procedure for Ferric and Ferrous Iron[1]*:* Transfer 10 drops of the extract to the spot plate. Add 3 drops of reagent A and 1 drop of reagent B. Stir, let stand 2 minutes. The resultant colors indicate amounts approximately as follows:

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[1] Introduced by Morgan (32) as a soil test.

Color	*Test*	*Relative Test Index*
Blue	Very high	10
Blue green	High	8
Apple green	Medium high	6
Pale green	Medium	4
Greenish yellow	Low	2
Lemon yellow	Very low	1

In this and subsequent iron tests, care should be taken to prevent the soil extracting solution or soil extract from coming in contact with any implement or piece of apparatus containing metallic iron.

Procedure for Ferric Iron: Transfer 10 drops of the soil extract to the spot plate. Add 3 drops of reagent A and 1 drop of reagent C. Stir and let stand 2 minutes. The resultant colors represent amounts approximately as follows:

Color	*Test*	*Relative Test Index*
Deep brownish red	Very high	10
Medium brownish red	High	8
Pale brownish red	Medium high	6
Very pale brownish red	Medium	4
Slight reddish tint	Low	2
Very faint reddish tint	Very low	1

Procedure for Ferrous Iron: Transfer 10 drops of the soil extract to the spot plate. Add 2 drops of reagent A and 1 drop of reagent D. Stir and let stand 2 minutes. The resultant colors and corresponding tests are the same as indicated for the above general iron test (ferric and ferrous).

A suggested alternate test for ferrous iron employs a reagent prepared as follows: A 1% aqueous solution of alpha-alpha-dipyridyl, acidulated with 1 ml of concentrated hydrochloric acid per 100 ml. Ten drops of the soil extract, treated with 2 drops of this reagent, give a deep red color when considerable ferrous iron is present, grading to no color when no ferrous iron is present. This is a somewhat more sensitive test than the one described above.

Sulfate Sulfur

Reagent: Dissolve 5 g of barium chloride in 100 ml of distilled water.

Testing Procedure: Transfer 10 drops of the soil extract to the test vial. Add 1 drop of the reagent. Shake vigorously and let stand for 5 minutes. The "line" chart as described for potassium on page 21 is used in reading the results.

Since this test is not sensitive over the range of concentrations existing in most soils of humid regions, except as a result of heavy applications of sulfate materials, it is not conducted as a routine procedure.

Nitrite Nitrogen

Reagent: Dissolve 1 g of sulphanilic acid, by gentle heating, in 100 ml of a saturated solution of ammonium chloride. Add 1.5 g of phenol and mix thoroughly.

Testing Procedure[1]*:* Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of the nitrite reagent, 1 drop of hydrochloric acid (1:1) and 4 drops of magnesium reagent B (15% NaOH). Stir and let stand 1 minute. The resultant colors may be rated from the following:

Color	*Test*	*Relative Test Index*
Yellowish orange	Very high	10
Orange yellow	High	7
Lemon yellow	Medium	4
Pale yellow	Low	2
Trace of yellowish tint	Very low	1

Soils very rarely show readable nitrite tests under normal field conditions.

Sodium

Reagent: Make up 2 separate lots as follows: (A) Uranyl acetate, 10 g; acetic acid (30%), 6 ml; make up to 65 ml with distilled water. Dissolve by heating. (B) Zinc acetate, 30 g; acetic acid (30%), 3 ml; make up to 65 ml with water. Dissolve by heating. Add (A) to (B) and continue heating until clear. Let stand several days and filter out the sediment.

Special sodium extracting solution: Add 2 ml of copper sulfate solution (10%) to 100 ml of distilled water.

Testing Procedure[1]*:* Since the Morgan soil extracting solution contains sodium, the soil must be extracted with special sodium extracting solution. The procedure of extraction is not otherwise different.

Transfer 5 drops of the extract, thus obtained, to a test vial. Add 20 drops (1 ml) of the reagent. Shake vigorously at 1 minute intervals for 10 minutes and compare, using the potassium "line" chart described on page 21.

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[1] Adapted from the test as employed by Spurway (43).

Soils in humid regions, except those receiving overflow water from oceanic tides, rarely show readable tests by this procedure. This test is especially applicable to alkaline conditions existing in arid soils.

Chloride

Reagent: Dissolve 2 g of silver nitrate in 100 ml of distilled water. Store in an amber glass-stoppered bottle.

Testing Procedure[1]*:* Since the Morgan soil extracting solution gives a precipitate of silver acetate when tested with the chloride reagent, the soil must be extracted with distilled water. If clear extracts cannot be obtained, a special chloride extracting solution is used[2]. The procedure of extraction is the same in other respects.

Transfer 10 drops of the soil extract to the test vial. Add 1 drop of the reagent. Shake vigorously and compare, using the potassium "line" chart described on page 21.

This test is valuable on saline soils, or when contamination from sea water or sea spray is suspected. Normal soils of humid regions rarely give readable tests, except when recently receiving liberal amounts of fertilizers containing chlorides.

Alternate Test for Chlorides

Reagent: Dissolve 4.25 g of silver nitrate and 2.7 g mercuric oxide in a solution of 10 ml concentrated HNO_3 in 50 ml of distilled water. Store in amber glass-stoppered bottle.

Testing Procedure[3]*:* Transfer 10 drops of soil extract to the test vial; run also a blank (10 drops of Morgan's soil extracting solution transferred to a separate vial). Add 2 drops of the reagent to each vial; shake vigorously. Add 2 more drops of the reagent to the blank as well as to the unknown. Shake and compare, using the potassium "line" chart described on page 21. A slight cloudiness (very low reading) indicates about 10 ppm of Cl; a low reading, 20 ppm; a medium reading, 80 ppm.

Carbonates

Testing Procedure: A soil containing carbonates in appreciable amounts is readily identified by the development of effervescence on the soil surface when the Morgan soil extracting solution is filtered through it. This usually results in the development of a convex soil surface at the end of the extraction. No quantitative measurement is attempted.

Soils high in carbonates also give extracts which show white precipitates on the addition of an alkaline reagent (ammonia reagent or magnesium

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[1] Adapted from the test used by Spurway (43).

[2] Special chloride extracting solution: Dilute 13 ml of nitric acid of ordinary concentration (70%) to 1 liter, using distilled water. This solution is approximately 0.2 N (33).

[3] Adapted from Montequi-Otero test for chlorides, Merck Index i.2863. Modified for Morgan Soil Testing System by T. R. Swanback, Windsor Tobacco Laboratory, Connecticut Agricultural Experiment Station.

reagent B). Normally this precipitate does not interfere with the color reactions and is due to the formation of calcium hydroxide in excess of its solubility.

Boron [1]

Reagent A: Glycerine in a dropper bottle (A. R. or C. P. grade analyzed glycerol).

Reagent B: Triple Acid. This is prepared from chemically pure concentrated HCl, H_2SO_4 and H_3PO_4 (85%), using equal quantities of each. First mix the HCl and H_3PO_4, then add the H_2SO_4 *slowly* in the open air, under a hood, or a short distance from a wall fan. The reaction is apt to be violent if the sulfuric acid is added too quickly. A gentle stirring with a clean glass rod will accelerate the "bubbling" period. The reagent is ready to use when cooled. Store in a clean glass-stoppered bottle, that previously has had a final rinsing with reagent B. The stopper should be loosely fitted to allow gas formed to escape.

Reagent C: Tumeric tincture. An excess of tumeric powder is added to 95% ethyl alcohol. Shake at intervals for about ½ hour and filter. Store in a dropper bottle.

Equipment: The glassware and spot plates used must be thoroughly cleansed in hot water (and in weak HCl solution when new and later occasionally) followed by distilled water. After air drying they should be stored away in clean paper when not in use. A spot plate should be used only once a day because *even a small amount of moisture* [2] *detracts from the sensitivity of the acid.*

Testing Procedure: A level teaspoon of soil is placed on the filter paper in the vial. (The soil used should preferably be a fresh sample which has not had an opportunity to air dry, having its original field moisture). Ten ml of Morgan's extracting solution is slowly (drop by drop at first) added to the soil. Let drain completely. Flush the extract with the inserted dropper pipette. Place 2 drops of the extract in DUPLICATE on the special spot plate. It is important that size of drops be consistently the same throughout the testing procedure. For blanks use 2 drops of Morgan's extracting solution (also in duplicate on the spot plate). In 3 more depressions place 2 drops of Morgan's extracting solution in each, to be used for wash basins. The dropper should deliver 18-19 drops per ml. Add 1 drop of glycerine (reagent A) and 2 drops of the triple acid (reagent B) to all depressions with solution and extracts in them. Add 1 drop of tumeric tincture (reagent C) to unknowns and to the blank, but NOT to the wash basins.

Wash a dropper pipette by pumping the liquid up and down 2 or 3 times in the "wash basin", successively in the first, second and third basin. Repeat the process in the blanks and mix blanks 1 and 2 together. Pro-

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[1] Modified from the Morgan testing procedure by T. R. Swanback, Windsor Tobacco Laboratory, Connecticut Agricultural Experiment Station.

[2] The plates should NOT be dried in an oven.

ceed to unknowns and mix the duplicates. If rank is known, begin with the weakest and operate towards the higher ones. If not known, rinse dropper in wash basins, and via blank proceed to unknowns.

Add 1 more drop of triple acid (reagent B) to all COLORED depressions (thus not to the wash basins), mix and compare colors with blank and standards. When the operator is familiar with the tests, it is not necessary to run standards with each test.

Interpretation: A perceptible pink color (deviating from the blank [1]) is indicative of sufficient boron for plant growth, corresponding to 0.4-0.5 ppm of boron. A peach color indicates 1 ppm boron. Deeper pink colors suggest surplus boron and are of interest for quality of product grown, provided boron is not present in toxic concentrations.

Boron tests should be calibrated carefully on the basis of standards prepared from boric acid dissolved in the Morgan soil extracting solution.

It has been noted that with soils giving high iron or aluminum tests the boron test color may be erroneously in evidence, while high amounts of nitrates tend to diminish the sensitivity of the test. Hence, if possible, the boron test should be confirmed by employing a laboratory procedure, such as the hot water extract method of Berger and Truog (2).

Zinc

Reagent A: Dissolve 0.0807 g of cobalt chloride in 100 ml of 0.5 N hydrochloric acid solution.

Reagent B: Dissolve 8 g of mercuric chloride and 9 g of ammonium thiocyanate in 100 ml of distilled water. Let stand for 3 or 4 days and decant the clear solution.

Reagent C: Ethyl ether.

Testing Procedure [2]*:* Place 1 level teaspoonful of soil in a 30 ml beaker. Add the Morgan soil extracting solution slowly, a few drops at a time, stirring the soil mass with a glass rod, until the soil is thoroughly wetted. Add an additional 5 ml quantity of the soil extracting solution. Stir for 1 minute. Filter. Transfer 10 drops of the extract to a test vial. Add 4 drops of reagent A and 10 drops of reagent B. Shake thoroughly and let stand for 2 minutes. Add 20 drops of reagent C. Shake gently and let stand for 10 minutes. The appearance of a blue color at the film of contact between the ether and the aqueous solution is evidence of zinc. A barely perceptible film of blue indicates approximately 10 ppm in the extract. Above about 25 ppm, a blue precipitate begins to accumulate in the bottom of the vial. The test should be compared with those obtained from standard amounts of zinc as zinc acetate, dissolved in the Morgan soil extracting solution. It has not yet been possible to

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[1] The blank should contain not more than a bare trace of pink color. If a definite pink color appears, it suggests that traces of boron may be present in the reagents, glassware or spot plates, or too much acid used. Note carefully the size of dropper used.

[2] Adapted from the method of Krumbholz and Sauchez (25).

calibrate the above amounts in the extract in terms of that which is active in the soil. However, the presence of considerable zinc, thus shown, is evidence of the accumulation of harmful concentrations, as occasionally found in the vicinity of industrial plants processing zinc ore or metal.

Copper

Reagent: Dissolve 5 g of alphabenzoinoxime in 100 ml of ethyl alcohol (95%).

Testing Procedure[1]*:* Prepare the soil extract as for the zinc test. Transfer 10 drops of the extract to the spot plate. Add 2 drops of the reagent. Stir and let stand for 5 minutes. A barely perceptible trace of greenish yellow color is observed when approximately 2 ppm of copper are present in the extract. The color deepens in greenish hue with higher amounts, being quite definite at 5 ppm; at 10 ppm, a good apple green color is developed. Readings of the test should be calibrated against standard amounts of copper as copper sulfate, dissolved in the Morgan soil extracting solution.

The copper test is especially useful in examining soils with considerable accumulations of spray residues.

Alternate Test for Copper[2]

Reagent A: Sodium fluoride, powdered.

Reagent B: Zinc acetate, 1% solution.

Reagent C: Ammonium mercury thiocyanate: Dissolve 8 g of mercuric chloride ($HgCl_2$) and 9 g of ammonium thiocyanate (NH_4CNS) in 100 ml of distilled water.

Standards: Standard copper solution containing 0.1% Cu++ or 1,000 ppm; weigh out 3.9281 g of cupric sulfate ($CuSO_4.5H_2O$) and dissolve in 200 ml distilled water. When dissolved, make up to 1 liter with distilled water.

By means of a calibrated pipette, prepare standards as follows:

Morgan Extracting Solution ml	*Standard Copper Sulfate Solution ml*	*Contains Cu++ ppm*
20.0	0.0	0
19.9	0.1	5
19.8	0.2	10
19.6	0.4	20
19.4	0.6	30
19.2	0.8	40
19.0	1.0	50
18.8	1.2	60
18.6	1.4	70
18.4	1.6	80

[1] Adapted from the method proposed by Hosking (21).
[2] Adapted from the method by King (23).

These may be made up and stored in stoppered vials for future use. All chemicals must be of C.P. grade or better.

Testing Procedure: Weigh out 10 g of recently air dried 20-mesh soil and add 10 ml of Morgan's extracting solution. Allow to stand for 5 minutes with frequent stirring. Filter. To the clear filtrate, add 0.2 or 0.3 ml of sodium fluoride (reagent A). Stir or pump several times with a dropping pipette.

Measure out carefully, by means of a calibrated pipette, exactly 0.2 ml of each of the standards prepared as indicated in the above table and place in separate depressions of a white porcelain spot plate. Do likewise with the unknowns. To each add 4 drops of reagent B; next, add 4 drops of reagent C. Stir each with a small glass rod and compare the intensity of the violet color of each of the unknowns with that produced by the standards.

Mercury

Reagent: Dissolve 0.1 g of s-diphenylcarbazide in 100 ml of ethyl alcohol (95%).

Testing Procedure[1]*:* Prepare the soil extract as for the zinc test. Transfer 10 drops of the extract to the spot plate. Add 2 drops of the reagent. Add 3 drops of sodium hydroxide solution (same as magnesium reagent B). Stir and let stand for 1 minute. A pale salmon red, from the indicator itself, is a negative test. A deep salmon red is observed when approximately 5 ppm are present in the extract. The color is a deep red at 10 ppm, violet red at 20 ppm, violet at 50 ppm, purple at 100 ppm. Readings of the test should be calibrated against standard amounts of mercuric chloride dissolved in the Morgan soil extracting solution.

The mercury test is occasionally useful in revealing mercury accumulations from fungicides containing this element. It confirms the indication of mercury in the phosphorus test, and is considerably more sensitive.

Lead

Reagent: Dissolve 0.05 g of dithizone in 100 ml of carbon tetra-chloride. This should be freshly prepared, since most glass containers contaminate the reagent after a few days of contact.

Testing Procedure[2]*:* Prepare the soil extract as for the zinc test. Transfer 5 drops of the extract to the test vial. Squeeze out 1 drop of the reagent upon the center of the liquid surface. The green colored spot thus formed should remain undisturbed. Observe during a 2-minute period. If the color of the spot remains green, no measureable amount of lead is present in the extract. At approximately 10 ppm (in the extract), an olive green hue develops in 2 minutes; at 20 ppm, the resultant

[1] Adapted from the method of Feigl and Neuber (16).

[2] Adapted from the method of Fischer (17).

color is olive brown; at 40 ppm - reddish brown; at 60 ppm - brick red within 1 minute; at 100 ppm - brick red in one-half minute.

The lead test is useful in identifying soils treated with lead compounds used in insect control, or soils contaminated with lead compounds as residues from sprayed crops. It should be noted that with the reagent used in the lead test, mercury compounds give a golden yellow color and zinc salts give a cherry red color.

Arsenic

Reagent A: Concentrated sulfuric acid.

Reagent B: Granular zinc A.R. (low arsenic content).

Reagent C: Silver nitrate solution (2 g silver nitrate in 100 ml distilled water).

Testing Procedure[1]*:* Prepare the soil extract as for the zinc test. Place a few grains of granular zinc in the bottom of a test vial. Add 5 drops of concentrated sulfuric acid. Add 10 drops of the soil extract. Place a disc of filter paper, approximately 15 mm in diameter, over the top of the test vial. Moisten the filter paper with 1 drop of silver nitrate solution (chloride reagent). Shake the vial gently several times, until gas bubbles are freely liberated. Let stand for 2 minutes. Examine the bottom side of the test paper disc. A faint yellowish or silvery sheen, with no perceptible darkening, is a negative test, the slight coloration resulting from other constituents that may be present. With increasing amounts of arsenic, the test paper shows darker spots. The test is sensitive to approximately 10 ppm in the extract.

The arsenic test is useful in studying arsenic accumulations and residues from insect control treatments, sprays and dusts.

Molybdenum [2]

Reagent A: Potassium xanthogenate (or xanthate) crystals[3].

Reagent B: A saturated solution of potassium xanthate in potassium thiocyanate (add sufficient potassium xanthate crystals to a 10% solution of potassium thiocyanate to obtain a saturated solution). Usually 5 ml is ample quantity to make at a time.

Reagent C: Hydrochloric acid, 1:1.

Testing Procedure: Transfer 10 drops of the soil extract to the spot plate and, for a blank, 10 drops of Morgan's extracting solution. Add a few crystals of reagent A and 1 drop of reagent C. Stir and watch

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[1] Adapted from the Feigl (15) modification of the original Gutzeit test.

[2] Adapted by T. R. Swanback from Feigl (15), p. 93.

[3] Although potassium xanthate may be obtained from chemical supply houses, it can readily be made in the laboratory out of ethyl alcohol, carbon disulfide and potassium hydroxide. $C_2H_5OH + CS_2 + KOH = KCS_2C_2H_5O + H_2O$.
Theoretically, the required quantities are 26% C_2H_5OH, 42% CS_2 and 32% KOH.

Cont'd. p. 33

color development. The slightest purple deviation of color from the blank indicates a *trace* of molybdenum, while a definite reddish blue signifies more than a trace.

In dealing with very small amounts of Mo (i.e. less than 1 ppm) the method may be made more sensitive by the following procedure:

To 10 drops of soil extract on the spot plate add 1 drop of reagent B and 1 drop reagent C. Do the same with the blank (10 drops of extracting solution).

A slight purple color appearing immediately upon adding the acid indicates at least ½ ppm of Mo. The color soon disappears. With only a faint pink color which quickly disappears, the molybdenum content is about 0.25 ppm.

ADAPTATION OF THE MORGAN TESTS TO PLANT TISSUE TESTING

The visible symptoms produced by serious deficiency or excess of a given constituent are frequently recognizable in plants by the trained observer. Such symptoms are well illustrated in a joint publication of the American Society of Agronomy and the National Fertilizer Association (1).

However, in the field the plant may suffer from deficiencies not sufficiently severe to produce definite symptoms, and further, it may suffer from combinations of several symptoms that are not readily identifiable. During the past few years numerous investigators have found it desirable to supplement quick tests of soils with similar tests conducted on fresh plant tissue or plant tissue extracts. By so doing, it has been frequently possible to verify cases of suspected crop deficiency or other nutrient abnormality.

Methods for such testing have been described by a number of investigators (9, 10, 11, 19, 38, 45, 47 and others). Some of the methods proposed are chiefly qualitative in character; some give semi-quantitative results, while others are meant to provide reasonably quantitative data. All three types are useful in their place.

Make a saturated alcoholic solution of KOH by adding an excess of KOH to ethyl alcohol, let stand several hours with occasional shaking (standing overnight results in a discolored solution).

Transfer 26 parts by volume of C_2H_5OH and 42 parts of CS_2 to a beaker, then add sufficient KOH (alcoholic) solution to make an initial white precipitate at the bottom of the beaker. If, upon stirring, a solid mass is produced, sufficient KOH has been added. After settling, pour off the supernatant liquid, and wash the precipitate once with ether.

Stir thoroughly under a hood or close to an exhaust fan, with the material spread out on a large watch glass. Dry overnight at room temperature in the dark.

After drying, break up lumps and mix thoroughly on wax paper, then transfer to an amber colored bottle. The salt should be a light yellow color.

Sampling

Since one of the main objectives in tissue testing is to secure quick results, the tests are always made on fresh plant material. A delay of a day or two is permissable if the sample is held moist under refrigeration. Because of the variability in composition with stage in growth, variety, weather conditions, and innumerable other factors, the tests should be made on a comparative basis, comparing abnormal with normal plants sampled identically and simultaneously.

The portion to be sampled depends upon the character of the plant and, in some instances, on the test to be made. For example, in testing corn, nitrate tests are best made on the basal part of the stalk, phosphorus on the stalk near the tassel, and potassium on the leaf sheath (10, 45). In the case of small grains, alfalfa, clover and similar crops, the stems are used for all tests, as are the blades of grass. Either the stems or the petioles are suitable for tests on beans, soybeans and potatoes; and for carrots and beets, the petioles. Where only one element is to be determined, a choice of plant parts can be made as described for the corn plant; for complete testing, it is sufficient to use the same portion for all tests. The practice at this laboratory for these tests has been to use the middle portion of the corn stalk, the stems of beans, and the basal portion of the stems of potatoes.

I. Rapid Field Tests (chiefly qualitative [1])

This method provides rough approximations of the amounts of nitrates, phosphorus, potassium, calcium and magnesium in plant tissues, and is of value only where abnormal plants or those having suspected deficiencies or excesses are compared with normal plants. The reagents, for the most part, are the same as those used in soil testing.

Nitrates

Either of the following reagents may be used.

Reagent A: Diphenylamine sulfuric acid. Dissolve 1 g of diphenylamine in 100 ml of concentrated sulfuric acid.

Reagent B: Sulfanilic acid-alpha-naphthylamine powder mixture (5). The mixture is prepared as follows:

(a) 100 g $BaSO_4$
(b) 10 g $MnSO_4.H_2O$
(c) 2 g finely powdered zinc
(d) 75 g citric acid
(e) 4 g sulfanilic acid
(f) 2 g alpha-naphthylamine

[1] A modification and adaptation from several methods (5, 34, 45).

Grind any coarse materials to a fine powder. Mix b, c, e, and f separately with portions of the $BaSO_4$. The whole, including a and d, is then mixed thoroughly. Use care to have room, table tops, etc., free of nitrate and nitrite. When stored in a fully blackened bottle, the reagent will keep several years.

Procedure for large leaves and stems: Apply a drop of reagent A to a freshly exposed cut surface; or sprinkle a little of the powder (reagent B) on the cut surface. Squeeze if necessary to wet the powder. With reagent A a deep blue color indicates an abundance of nitrates; with reagent B, a bright pinkish red means high nitrates.

Procedure for small stems or grass blades: Cut the plant material with a sharp knife or scissors into small pieces ¼″ or less. In the bottom of a clean 20 or 30 ml beaker place either 1 drop of reagent A or a small amount of reagent B (⅛ to ¼″ on the wide end of a toothpick), add some of the cut plant material and crush with the flattened end of a stirring rod directly on the reagent. Examine the beaker from below for color changes.

Phosphorus

To ¼ teaspoon or less of cut plant material in a small beaker, add 2 or 3 eyedropperfuls (2 or 3 ml) of Morgan's extracting solution, shake well; add 2 to 4 drops of phosphorus reagent A (p. 20), and 4 to 6 drops of reagent B. Observe color of the suspension. A strong blue indicates high phosphorus.

Potassium

Prepare plant material as for phosphorus. Add the Morgan extracting solution, then 2 or 3 drops of potash reagent A (p. 21) and about 15 drops of reagent B (p. 21). Shake well. Observe density of precipitate as compared with samples containing little or no potash.

Magnesium

Prepare plant material as for phosphorus. Add the Morgan extracting solution, then 2 drops of magnesium reagent A (p. 22) and about 6 drops of reagent B and shake well. To be sure of sufficient reagent, add a drop or two more of reagent B. A red color indicates high magnesium.

Calcium

Prepare plant material as for phosphorus and add the Morgan extracting solution. *CRUSH* the material well with the flattened end of a glass rod; add 2 or 3 drops of the calcium reagent (10% sodium oxalate, p. 22). Observe density of precipitate compared with a sample from which the reagent has been omitted.

II. Semi-quantitative Rapid Tissue Tests

These tests differ from those previously described (34) chiefly in the method of preparing the plant extract.

The sample is sliced thin with a razor blade or, in the case of grass and clover, cut into short lengths (¼"-⅓") with scissors. After mixing, 2.5 ml of the cut material (measured in an improvised container of that capacity) is placed in a test tube, 7.5 ml of the Morgan extracting solution (9 ml for grass) and up to ⅓ teaspoon of charcoal added, the contents shaken vigorously for 1 minute, then filtered. The clear extract is then tested by the quick test methods described earlier in this bulletin for soils, diluting wherever necessary. Readings are calculated to parts per million of *extract* [1].

III. Quantitative Tissue Tests

This method involves the use of the Waring blender for mincing the plant material, and a photoelectric colorimeter for reading colors of true solutions or opacity of suspensions. It is based on Wolf's (47) modification of Morgan's method. These procedures have been found to give satisfactory results on the plants tested (potatoes, corn, beets, spinach, beans, carrots and hybrid poplar petioles). The plant material is treated with the Morgan extracting solution identical to that used in soil testing, with the addition of activated charcoal (Darco G 60 or 97 or similar grade) as a clarifying agent.

A set of standard curves must be prepared in advance as described by Wolf (47). It is advisable to include a low and a high standard with every batch of samples. The procedures given below are designed for using shell vials (25 x 60 mm having a capacity of about 25 ml, and marked at 10, 15 and 20 ml) in a Lange photometer.

Preparation of the Plant Extract [2]

Ten g of fresh plant material, 200 ml of the Morgan leaching solution, and ½ teaspoon of charcoal are placed in a Waring blender and run for 3 to 5 minutes. Filter in 5½ cm Buckner funnels with suction, using S&S 597 or Whatman No. 1 paper. Transfer filtrate to 125 ml Erlenmeyer flasks. All aliquots are taken in duplicate.

Nitrates

Phenoldisulfonic Acid Method

Reagent A: Phenoldisulfonic acid. Dissolve 25 gm of pure white phenol in 150 ml of concentrated sulfuric acid, add 75 ml of fuming sulfuric

[1] Ppm of extract x 3 = approximate ppm of plant material for all crops except grass. For grass, ppm of extract x 3.6.

[2] Although the prepared extracts may keep several weeks or more in a refrigerator, some of them tend to get cloudy in a day or two; hence, it is better to run the analyses as promptly as possible, once the extracts have been prepared.

acid (containing 13-15% of sulfur trioxide) and heat at 100°C for 2 hours (48).

Reagent B: Sodium hydroxide, 15%.

Reagent C: Ammonium hydroxide diluted with water (1:1).

Testing Procedure: Place 1 to 4 ml of extract in a 50 or 100 ml beaker; add 2 or 3 drops of reagent B and evaporate to dryness on steam bath. Cool, add ½ to 1 ml phenoldisulfonic acid, stir or rotate. After 5 to 10 minutes add about 5 ml water, then make alkaline with reagent C. Make up to 20 ml with water. Read in the photoelectric colorimeter, using the BLUE filter. (If too concentrated, dilute to 100 ml, mix, and place 20 ml or so into vial for reading).

Standards: Use 0.5 and 2 ml aliquots of a 10 ppm standard solution, and proceed as described above.

Brucine Method

The brucine method can be used for plant tissue work if the aliquots are kept low.

Reagent A: Brucine 5%. Dissolve 1 g of brucine in 20 ml of chloroform.

Reagent B: Concentrated sulfuric acid, reagent grade (sp. gr. 1.84).

Testing Procedure: Pipette 0.2 to 2 ml of the plant extract in vial, dilute to 4 ml with Morgan's extracting solution; place vials in a cold water bath, add 0.2 ml (8 drops [1]) of brucine reagent and 8 ml of H_2SO_4 (slowly at first to prevent spattering [2]); mix thoroughly. After standing not less than 3 minutes nor more than 10, dilute to 20 ml with distilled water, mix thoroughly [3] and cool. Read in the colorimeter using the blue filter. The color is stable for at least an hour. If too concentrated, repeat test with smaller aliquot. For the blank use 1 ml of Morgan's extracting solution.

Standards: Use 1 and 4 ml aliquots of a 1 ppm standard solution, and proceed as described above.

Ammonia

Reagent A: Nessler's solution (See p. 20).

Reagent B: Sodium silicate, 10%.

Testing Procedure: Place 1 or 2 ml of the plant extract in vial, add 4 or 5 ml of ammonia-free water, then 0.2 ml of 10% Na_2SiO_3 (reason-

[1] It takes 8 drops of chloroform to equal 0.2 ml.

[2] To avoid breakage of vials when the H_2SO_4 is added, the following technique may be necessary: Remove the vial from the water bath, hold over an evaporating dish (to catch the solution if vial should break) and add the H_2SO_4 from a burette, slowly at first, with constant shaking or stirring. Then replace in water bath.

[3] A small motor mixer will be found helpful when a large number of samples are being run.

ably fresh), dilute to 20 ml with ammonia-free water, stir; add 1 ml of Nessler's solution. Read after 10 minutes using the BLUE filter. Consider 20 ml as total dilution. For the blank, use 1 ml of Morgan's extracting solution plus 19 ml of water.

Standards: Use 0.5 and 2 ml of a 10 ppm standard solution, and proceed as described above.

Phosphorus

Reagent A: Dissolve 2.5 g of ammonium molybdate in 100 ml of 6 N H_2SO_4 (18 ml of concentrated H_2SO_4 diluted to 100 ml).

Reagent B: Amino-naphthol-disulfonic acid. Dissolve 15 g of sodium bisulfite (anhydrous) in 100 ml of distilled water. To this add 0.5 g of pure, dry, 1 amino-2 naphthol-4 sulfonic acid, and 1.5 g sodium sulfite (anhydrous). Shake, make up to 500 ml, and store in brown bottle. (This solution is not good after it turns yellow).

Testing Procedure: Place 5 to 15 ml of the plant extract in vial; dilute to 15 ml with Morgan's leaching solution. Add 3 ml of ammonium molybdate solution, and stir. Add 2 ml of amino-naphthol-sulfonic acid, and stir. Read after 15 minutes using the YELLOW filter. Readings over 80 (% of total extinction) are unreliable. Use 15 ml of Morgan's leaching solution for the blank.

Standards: Use 1 and 5 ml of a 10 ppm standard solution, and proceed as described above.

Potassium

Reagent A: Sodium cobaltinitrite. Prepared as described on p. 21 but in larger quantities (4 x).

Reagent B: Iso-propyl alcohol. To 900 ml of iso-propyl alcohol add 100 ml of neutral formaldehyde.

Testing Procedure: Place 0.5 to 2 ml of the plant extract in the vial and dilute to 10 ml with the Morgan extracting solution. Add 1 ml of sodium cobaltinitrite solution and stir. After 1 minute add 10 ml of iso-propyl-alcohol (reagent B, preferably cold) slowly down one side of vial forming a layer of alcohol on top. In a few minutes rotate or stir [1] slowly at first, then rapidly until thoroughly mixed. Read after 10 minutes using the YELLOW filter. If reading is 80 or more on the colorimeter, repeat using a smaller aliquot. Use 10 ml of Morgan's extracting solution for the blank.

Standards: 1 and 5 ml of a 40 ppm solution and proceed as above. This procedure should be rigidly adhered to in all cases.

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[1] Use a rubber tipped stirring rod to avoid scratching the glass.

Calcium

Reagent: Sodium oxalate, 2%, prepared fresh daily. Shake before using. (It is possible to use an old solution made up at least a week in advance, providing one *always* uses an old solution. One must not switch from a fresh to an old solution or vice versa unless a separate set of curves is prepared for each).

Testing Procedure: Place 1 to 5 ml of plant extract in the vial, dilute to 20 ml with the Morgan extracting solution. Add 4 ml of the sodium oxalate reagent, and stir; read after 15 minutes using the BLUE filter. Use 20 ml of the Morgan extracting solution as a blank. Best readings on the colorimeter are obtained between 5 and 45.

Standards: 1 and 4 ml of a 100 ppm solution.

Magnesium [1]

Reagent A: Dissolve 0.02 g of Thiazol yellow in 100 ml of water. Store in an amber glass bottle.

Reagent B: Dissolve 20 g of hydroxylamine hydrochloride in water and dilute to 100 ml.

Reagent C: Dissolve 5 g thiourea in 50 ml of water.

Reagent D: Sodium hydroxide, 2.5 N. Dissolve 100 g of NaOH in water and dilute to 1 liter. Store in a Pyrex bottle or flask.

Reagent E: Starch - compensating reagent:

(a) Starch, 2%: To 2 g of C.P. soluble starch, add a few drops of water and make into a paste. Add slowly while stirring, 100 ml of boiling water (distilled). If it is necessary to filter the solution, do so while hot through a Whatman No. 31 paper. Prepare fresh daily.

(b) Compensating Solution: To 4.4 g $Ca(C_2H_3O_2)_2.H_2O$ and 0.37 g $Al_2(SO_4)_3.18\ H_2O$ in a 1-liter flask, add 10 ml of concentrated HCl and about 500 ml of water. Mix and dilute to 1 liter with water.

(c) Mix equal volumes of (a) and (b).

Standard Solution: Dissolve 0.8815 g $Mg(C_2H_3O_2)_2.4H_2O$ in 1 liter of Morgan's extracting solution to obtain a 100 ppm solution. Diluting this solution 1 to 5 with Morgan's extracting solution provides a 20 ppm standard.

Testing Procedure: Pipette 5 or 10 ml of plant extract into a vial, dilute to 10 ml with Morgan's extracting solution. Add 2 drops (0.1 ml) of reagent B, and stir; then 4 drops (0.2 ml of reagent C) and 4 ml of the starch-compensating reagent E(c), and stir. Then add 2 ml of Thiazol

[1] Peech and English method (36), with slight modifications proposed by Mikkelsen and Toth (27).

yellow and, after stirring, 4 ml of NaOH solution; mix thoroughly. Read in the colorimeter, using the GREEN filter. The color is constant for an hour or more. Use 10 ml of Morgan's extracting solution for the blank. Readings above 70 on the colorimeter are less reliable.

Standards: Use 1 and 4 ml of a 20 ppm solution, and proceed as described above.

Calculations

Determine ppm in the solution as read, then calculate to determine concentration in the plant, as follows:

$$\text{ppm in plant} = \frac{\text{ppm of solution} \times \text{total dilution}^{1} \times \frac{\text{ml of extracting solution}^{2}}{\text{aliquot (ml)}}}{\text{g of plant material}}$$

$$\text{e.g.} \quad \frac{0.40 \times 20 \times \frac{200}{4}}{10} = 0.40 \times 100 = 40 \text{ ppm}$$

$$\text{e.g.} \quad \frac{8.2 \times 21 \times \frac{200}{2}}{10} = 8.2 \times 210 = 1722 \text{ ppm}$$

QUANTITATIVE CALIBRATION OF TEST CHARTS

Color charts for reading concentrations of various elements found in the soil extract are given in the Appendix of this bulletin [3].

These charts were based initially on the assumption that when 10 ml of Morgan's extracting solution is percolated through the soil, a given constituent is extracted in a fairly definite ratio to the total amount that could be extracted by a series of repeated extractions. On this basis, the first extraction approximates the following percentages of the total amount thus extractable:

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[1] Total volume (ml) of the solution in the vial used in the colorimeter.

[2] Amount of Morgan's extracting solution used in the preparation of the plant extract.

[3] The assistance of Mrs. Marion Kirk in the preparation of the color charts is gratefully acknowledged.

Constituent		*Per Cent Extracted*
Nitrate nitrogen	—	80
Ammonia nitrogen	—	50
Phosphorus	—	4
Potassium	—	50
Calcium	—	50
Magnesium	—	50
Aluminum	—	10
Manganese	—	20
Iron	—	20
Sulfur	—	80
Nitrite nitrogen	—	80
Sodium	—	60
Chlorides	—	80

In connection with the foregoing percentages, it is of interest to note that practically all of the nitrate and similar water-soluble constituents are removed by 4 successive extractions. The exchangeable bases, such as potassium, calcium and magnesium, are obtained in 6 or 7 portions. On the other hand, the phosphorus concentration of the second extract is usually slightly higher than the first. Successive extractions diminish only slightly in phosphorus content, even up to the twentieth portion. Aluminum and iron diminish slowly in concentration for 6 or 7 extractions, and thereafter remain practically constant, with definite amounts of these constituents proportional to the amount in the first extract.

In Bulletins 372 and 392 (32, 33) these relationships were used to calculate the number of pounds per acre to plow depth that would be represented by the test. Such an expression of results provides a helpful concept in evaluating the magnitude of the test, but has been frequently misused, or applied too literally, in the interpretation of results by some soil testing laboratories using these methods. In Bulletin 450 (34) it was replaced by a Relative Test Index scale of 1 to 10. For general use, this appears to be preferable as it eliminates the objection cited above and simplifies comparisons between tests. In this bulletin the number of colors has been reduced to four (Relative Test Index Numbers 2, 4, 6, 8). However, to meet the need in certain situations and for the benefit of those who are accustomed to think in terms of specific concentrations, the results are expressed in parts per million (ppm) as well as in the arbitrary units of 2 to 8. Doubling the ppm approximates the pounds per acre on a plow depth basis (6-7 inches).

Composite Solution Standards for the Calibration of the Charts

The color and turbidity charts given in this bulletin are the results of the best efforts of the engraver and printer. However, it is very difficult to obtain exact color reproductions by the photo-engraving process. It is desirable to check them with solutions containing various concentrations representing the ranges of sensitivity of the tests. Furthermore, there may be those who wish to extend the limits of the charts, i.e. include very low (relative index 1) and very high (relative index 10).

The following scheme employs a series of single stock solutions for each of the constituents in the routine tests. These are combined in a series of three mixed stock solutions which may be kept ready for reference at any time. The mixed stock solutions are combined and diluted in varying proportions in order to furnish convenient quantities for immediate comparisons. (Calculations from the exact concentrations employed, through the successive mixtures and dilutions, should not be used in an exact quantitative sense when such a mixed standard is employed).

1. Prepare separate solutions for each constituent, dissolving quantities of the C.P. chemical shown in the following table in *100 ml* of the *Morgan soil extracting solution:*

Constituent	*Chemical formulae*	*G per 100 ml*	*Concentration of constituent ppm*
Nitrate Nitrogen	$NaNO_3$	0.182	300
Ammonia Nitrogen	$(NH_4)_2SO_4$	0.473	1,000
Phosphorus	NaH_2PO_4. H_2O	0.036	80
Potassium	KCl	0.191	1,000
Calcium	$Ca(C_2H_3O_2)_2$. H_2O	6.590	15,000
Magnesium	$Mg(C_2H_3O_2)_2$. $4H_2O$	0.441	500
Aluminum	$AlCl_3$. $6H_2O$	0.448	500
Manganese	$MnSO_4$. $4H_2O$	0.162	400

2. Prepare three mixed stock solutions from the above separate solutions:

Mixed Stock Solution A

20 ml of NO_3-N (300 ppm)
10 ml of NH_4-N (1,000 ppm)
10 ml of P (80 ppm)
10 ml of Mg (500 ppm)

Mixed Stock Solution B

10 ml of K (1,000 ppm)
10 ml of Ca (15,000 ppm)
30 ml of Morgan's soil extracting solution

Mixed Stock Solution C

10 ml of Al (500 ppm)
10 ml of Mn (400 ppm)
30 ml of Morgan's soil extracting solution

For ready use, the above solutions may be kept in 2-ounce dropper bottles.

3. To calibrate the charts, set up a series of 6 one-half ounce glass vials, numbered to correspond to the Rating Index Numbers. A 10 ml mark should be made on each vial.

The amounts of the three mixed stock solutions[1] to be added to each vial are as follows, in drops:

Relative Test Index	*1*	*2*	*4*	*6*	*8*	*10*
Mixed Stock Solution A	1	3	6	12	18	30
Mixed Stock Solution B	8	14	20	25	30	35
Mixed Stock Solution C	1	3	6	12	18	30

Make up the contents of each vial to the 10 ml mark with Morgan's extracting solution. Mix thoroughly. Test for each constituent as usual, except for Al, when *4 drops,* undiluted, should be tested.

The special tests may be calibrated with appropriate solution standards prepared from pure salts dissolved in the extracting solution and diluted to their proper range of sensitivity.

APPLICATION OF TESTS TO DRAINAGE WATER FROM SOILS, IRRIGATION WATERS, ETC.

It is frequently desirable to obtain a rough picture of the relative amounts of various soluble chemical constituents in the drainage water from soils, water used for irrigation purposes, or from springs, wells and streams. The tests used for soil extracts can be applied for this purpose, although a few adjustments are required to compensate for the poor buffer action of such dilute solutions. Toluene, sometimes added to stop bacterial action, must not be used on samples to be tested. The modifications are indicated below for the various routine and special tests that are thus affected.

Ammonia nitrogen: Use only 1 drop of the test reagent.

Phosphorus: Use only 5 drops of the water, adding 5 drops of the Morgan soil extracting solution. Use only 1 drop of reagent B.

Calcium: Add 2 drops of the Morgan extracting solution to 10 drops of the water and mix before adding the test reagent.

Magnesium: Add 5 drops of the Morgan extracting solution to 10 drops of the water and mix before adding the test reagents. Use only 2 drops of reagent B (15% NaOH) in developing the test.

Aluminum: Use 4 drops of the water, add 1 drop of the Morgan extracting solution and mix before adding the test reagent.

Manganese: Add 1 drop of 1:3 acetic acid (1 part glacial acetic acid to 3 parts of distilled water) to 10 drops of the water and mix before adding the reagents.

Copper: Add 2 drops of the Morgan extracting solution to 10 drops of the water and mix before adding the reagent.

Carbonates: Place 2 ml of the water in a test vial that has been very thoroughly rinsed with distilled water. Add 1 drop of phenolphthalein indicator (prepared by dissolving 0.5 g of phenolphthalein powder

[1] Inasmuch as Stock Solution C tends to interfere with the magnesium test, it is better to test C separately.

in 50 ml of ethyl alcohol and diluting to 100 ml). A pink to red color indicates the presence of carbonates. Add standard $KHSO_4$ solution (0.034 g of potassium acid sulfate dissolved in 100 ml of distilled water), drop by drop, until the pink color entirely disappears, after shaking. Each drop thus required is equivalent to 50 parts of carbonate (CO_3) per million in the water tested.

In case it is desired to estimate *bicarbonates* (HCO_3), add 1 drop of methyl orange indicator (0.1 g methyl orange in 50 ml ethyl alcohol diluted to 100 ml with distilled water), and continue the addition of $KHSO_4$ solution, drop by drop, until the yellow orange color changes to reddish orange. Each drop of $KHSO_4$ solution required, not including the amount required to decolorize the phenolphthalein, is equivalent to approximately 75 parts of bicarbonate (HCO_3) per million in the water tested.

The other tests (NO_3-N, K, Fe, S, NO_2-N, Na, Cl, B, Zn, Hg, Pb, As) are conducted exactly as previously described in the section on soil extract testing, and including very low and very high readings (beyond the limits of the color charts).

Quantitative estimations in water tests: It is possible within the range of sensitivity of the test to make a fair estimate of the concentration of the various soluble constituents in water thus tested. Results are suitably expressed in terms of parts per million. The following table indicates the approximate amounts thus indicated, based on the use of the charts or described colors.

TABLE 3. APPROXIMATE QUANTITATIVE INDICATIONS IN WATER TESTS

Constituent	Relative Test Index Number					
	1	2	4	6	8	10
	ppm	ppm	ppm	ppm	ppm	ppm
Nitrate nitrogen	0.3	0.9	1.8	3	6	12
Ammonia nitrogen	1	3	5	10	20	40
Phosphorus	0.2	0.5	1.0	1.9	2.9	4.8
Potassium	8	14	20	24	28	32
Calcium	100	150	200	300	400	500
Magnesium	0.5	1	2	5	10	20
Aluminum	0.5	1	2	5	10	20
Manganese (A and B reagents only)	0.5	1	2	4	8	16
Iron	1.5	3	5	10	25	50
Sulfate sulfur	50	100	200	300	400	600
Nitrite nitrogen	0.5	1	2	4	6	10
Sodium	120	180	240	360	480	600
Chlorine	25	50	100	200	400	800
Boron	Sensitivity range:		2 to 50 parts per million			
Zinc	"	"	5 to 50 " " "			
Copper	"	"	2 to 25 " " "			
Mercury	"	"	5 to 100 " " "			
Lead	"	"	10 to 100 " " "			
Arsenic	"	"	10 to 100 " " "			

ADAPTATION OF QUICK TESTS TO SALINE OR ALKALI SOILS

The method of soil extraction with an acetic acid-sodium acetate buffer solution, such as employed in the Morgan Soil Testing System, is primarily adapted to soils of humid regions, containing relatively low amounts of water-soluble salts, and either acid or only slightly alkaline (below 8.2 pH) in reaction.

Saline or white alkali soils contain large amounts of water-soluble salts, such as the chlorides and sulfates of sodium, magnesium, and calcium. When the salt concentration is fairly high (3,000 ppm or more), a mixture of the soil with distilled water - for instance, 1 level teaspoonful per 10 ml of distilled water - is sufficiently flocculated by the presence of the salts to yield a clear water extract upon filtration. However, if the salt concentration is low, or if the soil is deflocculated by the presence of alkali carbonate, a clear water extract is not obtained.

A suitable procedure for obtaining clear, colorless extracts of soils that may be reliably tested for the common alkali or saline constituents is as follows:

> Place 1 teaspoonful of the soil in a 30 ml beaker. Add 10 ml of distilled water to which from 1 to 5 drops of a neutral 1% copper acetate solution has been added. (Heavy soils low in salts require more copper acetate to effect clarification. Use no more than is actually necessary to give a clear filtrate). Stir thoroughly for 1 minute, and filter through a paper of the quality used in the usual procedure.

The extract may be subjected to various tests following the techniques recommended for drainage waters, etc. The copper test, of course, cannot be included. The most useful tests are those for chlorides, sulfates, nitrates, sodium, calcium, magnesium and potassium.

Soils high in sodium and potassium carbonates are known as black alkali soils. The carbonates dissolve and disperse the organic matter which diffuses through the soil and colors it dark brown or black. Black alkali soils yield extracts showing the presence of soluble carbonates by the phenolphthalein indicator. However, a pH test of the soil should be employed to confirm the presence of alkali. (Black alkali soils are indicated by pH tests above 8.5).

THE INTERPRETATION OF SOIL TESTS

Soil test data should be considered with reference to the limiting effects on crop growth that may be expected from other factors, such as the following: poor aeration or restricted root system caused by undesirable soil structure or soil tilth, deficient drainage, low organic matter content, unfavorable seasonal conditions, plant pests, and plant diseases. Irrespective of the chemical fertility of the soil, the crop expectation is less than normal when one or more of these factors is in operation. It is impracticable to seek to attain the most desirable tests on soils otherwise restricted in productive capacity.

The economic productive level of the crop under consideration determines to a marked degree the extent to which one can afford to build up the fertility level of the soil. Fertilizers can be profitably applied in much larger amounts for crops capable of giving high net returns per acre [1]. This is conspicuously true of intensive vegetable crops, tobacco or potatoes, as contrasted with corn, small grain, hay and similar crops.

Soil tests should be compared in the light of past practices with respect to fertilizers, manures and lime. Many obvious correlations may be observed. On the other hand, when the soil treatment has been so favorable as to justify an expectation of relatively high ratings for phosphorus, potassium and calcium, and a low test for aluminum, the explanation for less desirable tests should be sought, giving consideration to the fixing power of the soil and the degree of exhaustion of available constituents that could be accomplished by crop withdrawal.

Some tests, notably those for nitrate and ammonia nitrogen, depend upon temporary conditions [2], such as the activities of soil micro-organisms, seasonal effects (abnormally wet and dry periods) and amount of leaching that has been going on. A test may be given much weight, or entirely disregarded, depending upon weather or other environmental conditions and cropping practices which may have accentuated the soil conditions in question.

The interrelation of various quick tests and the pH test should be especially considered. Chemical soil fertility is best estimated from a study of the composite pattern thus presented.

No definite limits for favorable or unfavorable soil tests can be set for a given constituent, even for a particular crop, which will apply under all conditions. Sound judgment, thorough agronomic training and much experience in the applying of the results of soil tests on soils of known performance are all essential to the diagnostic interpretation of soil tests in terms of soil management practices.

The practical value of the tests is limited chiefly by the qualifications of the person who is responsible for translating the data into amounts and kinds of fertilizers, manures, lime and other soil amendments or treatments that are most likely to be effective in promoting profitable crop production.

A laboratory technician who can follow simple chemical routines can be easily and quickly trained to make the tests described in this bulletin. For best results he should be given constant guidance and supervision. *But if poor soil samples are submitted to the laboratory, poor results may be expected. The best laboratory technique is not a substitute for carefully taken samples.*

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[1] In the Connecticut Valley, for example, profitable applications of as much as 200 pounds per acre of nitrogen, 120 pounds of phosphorus (P_2O_5) and 200 pounds per acre of potash are made to tobacco (Shade, broadleaf, Havana seed).

[2] Large quantities of ammonia develop soon after fertilization of tobacco fields.

Soil test interpretations are based upon experience obtained in applying soil test results to many hundreds of actual cases and to soils that have been exhaustively studied both by laboratory analyses and by crop responses to various treatments in greenhouse and field experiments. At this Station, experience has been obtained from thousands of soils tested, chiefly on Connecticut soils, and on many experiments that have been conducted in the greenhouse and field. Such experimentation is continuing in one form or another to test new ideas on soil and plant tissue testing.

In previous bulletins (31, 32, 33, 34) details pertaining to general soil test interpretations were included in the last section. Since interpretations worked out for Connecticut cannot be used extensively elsewhere, they have been omitted from this publication. Helpful information on plant nutrient requirements and interpretations for soil and crop testing are available elsewhere (1, 10, 20, 22, 24, 29, 35, 42). For those interested, it is suggested that reference be made to these excellent publications.

Soil Reaction (pH) Tests

As previously stated, pH tests do not directly indicate lime needs. The amount of lime required to change a soil from a given pH value to a higher, less acid-indicating one, depends not only upon the change

TABLE 4. SOIL LIME-REQUIREMENT GROUPS SEPARATED ON THE BASIS OF TEXTURE, ORGANIC MATTER AND CATION EXCHANGE CAPACITY

Soil Group	Lime Requirement	Textural Class	Organic Matter Content Approximate Per Cent	Cation Exchange Capacity [1]
I	Very Low	Loamy sand	2-4	4-6
↓	↓	Sandy loam	1-3	
II	Low	Loamy sand	5-7	7-10
↓	↓	Sandy loam	4-6	
		Fine sandy loam	2-4	
III	Medium	Sandy loam	7-10	11-15
↓	↓	Fine sandy loam	5-7	
		Loam	3-5	
IV	High	Fine sandy loam	8-10	16-20
↓	↓	Loam	6-8	
		Clay loam	3-6	

[1] Milligram equivalents per 100 g of soil.

in pH to be effected, but also upon the cation exchange capacity of the soil, chiefly as related to the organic matter and clay content of the soil within a given region. For example, the soils of Connecticut may be roughly classified into four groups, as shown in Table 4.

The degree of pH adjustment in the positive direction that is desirable depends upon the minimum pH at which the crop will give normal production on an otherwise favorable soil. Crops vary considerably in their range of adjustment to varying pH levels. Tolerant soil acidity ranges for practically all crops grown are given in tabular form by Hester and Shelton (19), Small (40), and Spurway (41).

Soils with low to very low magnesium tests should be limed with dolomitic (magnesian) lime if the pH test indicates that lime is needed. If the pH is sufficiently high so as not to require lime, magnesium should be used as magnesium sulfate or "double manure salts".

If the calcium is very low, and the magnesium test is very high, the liming preferably should be in the form of a "high-calcic" material.

Conditions Indicated by Various Quick Tests

Nitrogen Tests (ammonia, nitrite and nitrate)

Nitrogen exists in the soil largely in the form of partially decomposed organic residues containing proteins. Micro-organisms (bacteria and fungi) gradually transform this nitrogen into ammonia compounds. Organic nitrogenous fertilizer materials and leguminous crop residues are more readily attacked due to their high protein content. Urea and cyanamid are fertilizer materials that can be rapidly hydrolyzed to produce ammonia compounds, while nitrogen in the ammonia form is directly supplied in fertilizers containing sulfate of ammonia, ammoniated phosphates, or ammonium nitrate.

Nitrogen in ammonium compounds under certain conditions may be utilized as such by many plants, especially during their early growth, thus consuming the supply as indicated by the test. However, the chief reason the ammonia test fails to reveal more than small amounts present under normal field conditions is due to the rapid change of ammonia to nitrites and nitrates by bacterial activity. The change to nitrates is usually rapid in comparison with that of the earlier stages of nitrogen transformation. Therefore, only a few weeks after fertilizer applications supplying ammonia have been made, little or no ammonia nitrogen and no nitrite can be identified by the tests. Except during a short period after such fertilizer treatment, a substantial ammonia test is an indication of unfavorable conditions for nitrification, such as high acidity, excessive or deficient moisture supply, or other disorders.

Inasmuch as a high content of ammonia may affect the potassium test, it is particularly desirable to test for ammonia whenever an unusually high potassium test is obtained.

Nitrites are rarely found except as a temporary condition occasionally resulting from a very heavy nitrogenous fertilizer treatment which was

not well mixed into the soil, especially under poor soil aeration resulting from excess moisture. Nitrite tests in more than trace amounts should be considered as harmful. Instances of severe injury to plant growth have been noted on soils showing medium to high readings.

Nitrate nitrogen, whether formed in the soil through nitrification of ammonia derived from organic residues and fertilizer materials, or directly supplied in the fertilizer, (viz., nitrate of soda), is rapidly assimilated by the roots of living plants and may be readily lost from the soil by the percolating action of heavy rains. Hence, high tests for nitrate nitrogen in field soils are to be expected only when the root system of the crop is not yet fully developed [1].

High tests indicate a large reserve of readily available nitrogen for the use of the crop. Rapidly growing annual crops require a large reserve during the period of most active growth. The gradual processes of nitrogen liberation are rarely sufficiently rapid to meet their requirements at that time. Crops with perennial root systems, such as sod grasses, shrubs and trees, take up nitrogen through a much longer period of the year, and low nitrate tests do not necessarily indicate a lack of available nitrogen.

Low tests are to be expected at the end of the cropping period, during winter and early spring, and after a period of heavy rainfall. Under such conditions, when all other factors are favorable, the absence of nitrates may not necessarily indicate poor availability of soil nitrogen, but the crop is apt to respond to the addition of a readily available nitrogenous fertilizer.

Abnormally high nitrate nitrogen tests are occasionally encountered in greenhouse and other intensively fertilized soils, and suggest possible injury to the crop due to an excessive concentration of the nitrate salts. Such a condition may be corrected by leaching the soils with large amounts of water, provided the soil does not contain too much clay.

Thus, the nitrogen tests may either be given much significance or practically disregarded, depending upon whether or not conditions are favorable to the development of an accumulation of these mobile constituents.

Since factors other than the soil test are usually important in assessing the amount of available nitrogen that is likely to be supplied by the soil during the active growing period of the crop, it is helpful to recognize soil characteristics and management practices that are usually involved in rating a given soil as to its potential fertility. They may be grouped into the following *Nitrogen Availability Classes:*

I - *High:* Liberal manure applications (such as 15-25 tons of stable manure) within a few months preceding the crop; unusually favorable amount of soil organic matter, as indicated by a dark soil color, provided the soil is well drained and not strongly acid; high to very high nitrate nitrogen soil tests.

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[1] Except tobacco, where relatively high tests of NO_3-N are desirable.

II - *Medium High:* Light manure applications (8-14 tons of stable manure) within a few months preceding the crop; a large green manure or a heavy clover or alfalfa sod plowed under; medium to medium high organic matter, as indicated by medium dark soil color; favorable drainage conditions; medium high nitrate nitrogen soil tests.

III - *Medium:* Average cultivated cropping conditions, or with grass sod plowed under or undisturbed grass sod as in pastures and lawns; loamy soil texture, with fair organic matter content; medium nitrate nitrogen soil tests.

IV - *Low:* Cultivated crops on sandy soils of relatively low organic content; low to very low nitrate nitrogen soil tests.

Phosphorus Test

Phosphorus occurs in unfertilized and virgin soils in slowly soluble mineral and organic combinations. It is a component of all mixed fertilizers, and is frequently applied alone as superphosphate or bone meal.

Under high levels of fertilization, in excess of 500 pounds per acre per year of fertilizers containing 8 per cent or more of phosphoric acid (P_2O_5), crops remove less phosphorus than is applied to the soil. This element is not leached out of the soil. In soils only moderately acid, applied phosphates remain for long periods in a fairly available form. On highly acid soils, containing much active aluminum and iron, phosphorus combines with these compounds to form aluminum and iron phosphates which are largely unavailable to plants. At low rates of fertilization, the amount of phosphorus applied results in little or no accumulation, and there may be a net loss when only small amounts of manure or fertilizer are used. When such a soil receives little or no lime, low phosphorus availability is a common condition.

The phosphorus test indicates the level of the more readily available phosphorus in the soil, either native or as a residue from previous applications. Crops show marked differences in their capability to thrive at the different degrees of phosphorus availability shown by this test. Most market garden crops, potatoes, tobacco, and many legumes require applications of phosphatic fertilizers unless tests show high amounts of available phosphorus. Many soils showing only *medium tests* grow good grass, hay, corn, oats, and alsike clover with very little phosphorus fertilization, if otherwise in a fertile state. Low or trace readings indicate the necessity for proportionally high amounts of phosphoric acid in the fertilizer, depending upon the crop grown.

The active phosphorus content of the soil is a fairly stable property, except as affected by recent fertilizer application. Soils which have received applications of arsenical materials may give high tests, regardless of their phosphorus content. Hence, results in such cases are subject to question.

At a given level of phosphorus availability, high pH values (5.6 or above) tend to increase the test reading. On the other hand, at high degrees of acidity (below pH 5.0), considerable amounts of slowly available aluminum and iron phosphates may be present in soils giving low

tests. Reasonable allowance should be made for this factor, especially on soils known to have received considerable amounts of phosphorus in fertilizer applications in recent years.

The following conditions are usually considered in determining the *Phosphorus Availability Classes:*

I - *High:* Liberal applications of complete fertilizers for several years, especially on a sandy soil; a slight degree of acidity; a low aluminum soil test; high to very high phosphorus soil test.

II - *Medium High:* Moderate applications of complete fertilizers for several years; light loam or sandy loam texture; moderate to slight acidity; a medium aluminum soil test; medium high phosphorus soil test.

III - *Medium:* Light, infrequent fertilizer applications; a strong degree of acidity; a medium to high aluminum soil test; medium phosphorus soil test.

IV - *Low:* No fertilizers on previous crops; a loam, silt loam or clay loam soil; a very strong degree of acidity; a high or very high aluminum soil test; low to very low phosphorus soil test.

Potassium Test

Potassium occurs in soils in large amounts in the form of rock minerals that are difficult to dissolve. Their gradual decomposition liberates small quantities of potassium which are loosely combined with colloidal material (clay and humus) capable of being displaced into the soil solution by cation exchange reactions.

Potassium may be added to the soil in fertilizers containing potash, or as manures or crop residues, and is largely transferred into the exchangeable form. Some potassium is removed from the soil by leaching, especially in cultivated and liberally fertilized soils.

The active potassium of the soil, best capable of nourishing the crop, is that which exists in exchangeable form, or in true solution. Quick tests indicate such supplies of this constituent.

Active potassium may be removed from the soil more rapidly than it is replenished by natural processes. Thus, tests may be lower at the end of the growing season especially after a crop having high potash requirements, than where the soil has been fallow or supporting little vegetation for several months. Hence, most reliable tests are obtained in the spring, prior to fertilization.

In soils which have been liberally treated with potassium fertilizers, a portion of the potassium may become fixed in a non-exchangeable form and thus not recoverable by the methods of extraction described in this bulletin. Such forms, however, are more available to the crop than is the potassium in native soil minerals. Reasonable allowance for this factor should be made.

The following conditions are usually considered in determining the *Potassium Availability Classes:*

I - *High:* Heavy applications of complete fertilizers, supplying from 120 to 200 pounds of potash per acre annually, or heavy treatment with manure of good quality; a loamy soil texture; calcium or magnesium soil tests not unusually high in relation to the potassium soil test; high to very high potassium soil test.

II - *Medium High:* Moderate applications of complete fertilizers, supplying from 40 to 100 pounds of potash per acre during recent years; fair applications of manure of good quality; intensive cropping; a medium heavy soil texture; medium high potassium soil test.

III - *Medium:* Intensive cropping, irrespective of past fertilizer treatment or under average cropping, with little or no fertilizer or manure, or with manure of poor quality (badly leached); medium to low potassium soil test.

IV - *Low:* No fertilizer or manure; very sandy soil texture; low to very low potassium soil test.

Calcium Test

Calcium in soils occurs in the form of undecomposed carbonates (in calcareous soils), rock minerals, as exchangeable calcium (adsorbed by the soil colloids) and as soluble calcium salts. Acid soils contain no carbonates and little exchangeable calcium. However, many soils which show a considerable degree of acidity by pH tests may have a fair amount of exchangeable calcium. This is especially true of soils high in organic matter or active mineral colloids. In many cases the calcium test is a better indication of lime needs than is the pH test.

Soils with high and very high calcium tests contain adequate amounts of calcium for all crops. Usually they do not respond to liming unless a high active aluminum concentration is indicated. Medium calcium tests on soils near the neutral point may be expected on light sandy soils, but a medium test on acid soils calls for lime if alfalfa, sweet clover and lime-loving vegetable crops are to be grown. A low calcium test on soils with a high aluminum test is a certain indication of a need for lime for all except the most acid-tolerant plants, such as blueberries, strawberries, or ericaceous shrubs. When a trace reading is obtained, lime should be used in liberal amounts for most crops, except in those cases where such treatment intensifies disease injury.

Certain disease-producing soil organisms seem to be closely related to the available calcium in the soil, in relation to the other bases, especially potassium and magnesium. Thus, club root of cabbage is made less severe by increasing the calcium supply. Physiological root disturbances, such as the brown root rot of tobacco (caused by soil nematodes), are frequently favored by calcium deficiency. On the other hand, the black root rot of tobacco and the scab organism which attack potato tubers become more troublesome on soils with higher relative amounts of calcium.

It must be borne in mind that, unless all other tests are satisfactory, heavy liming may produce an unbalanced soil condition. Thus, liming has frequently proven injurious on many sandy soils, especially in the southern United States, which are deficient also in other elements such as magnesium, manganese, potassium or iron. Excessive applications of

lime may depress the availability of boron in the soil, especially for crops requiring high amounts of soluble boron. Deficiencies of boron and manganese in soils are accentuated by liming treatment.

Magnesium Test

Magnesium occurs in soils in the following forms: dolomitic carbonates, unweathered minerals, exchangeable magnesium adsorbed by soil colloids, and soluble magnesium salts.

High and very high tests for magnesium are obtained from calcareous soils derived from dolomitic limestones, and from moderately acid soils resulting from the weathering of rocks high in ferro-magnesium minerals. Medium tests are more common on soils of moderate acidity, on calcareous soils from high calcic limestones, or on soils which have been moderately limed with material of dolomitic origin. Soils which have been fertilized over a period of years with acid-forming fertilizers containing no magnesium produce soils low in magnesium. Low tests are common on acid soils, and very low or negative tests may occur on strongly acid soils. This is particularly true of sandy soils. In such cases a carrier of magnesium should be applied in the form of dolomitic lime.

On soils giving high calcium and trace magnesium readings, or where pH values are as high as desired for the crop, magnesium sulfate or other neutral magnesium compound may be used to supply magnesium without sweetening the soil. Commercial fertilizers thus formulated are now on the market.

Aluminum Test

Aluminum occurs in large amounts in all soils, in the form of undecomposed minerals and in the inorganic colloidal material. In neutral, slightly acid or slightly alkaline soils, the element is in inert combinations that have no direct effect upon plant growth. At greater degrees of acidity, aluminum becomes active, capable of combining as soluble salts, and may exert an adverse effect upon the growth of many plants, especially those which are benefited by liming when grown on acid soils.

A high or very high test is indicative of an undesirably acid soil, upon which acid-sensitive crops are almost certain to fail. A medium test is not serious, especially with grasses, corn, oats, potatoes and tobacco. A low or negative test is desirable, except for distinctly acid-tolerant plants.

Manganese Test

Manganese occurs in small amounts in all soils, chiefly in relatively insoluble combinations. In some calcareous soils and acid soils that have been heavily limed, practically no manganese is present in active forms, and some crops are unable to obtain even the small amounts necessary to meet their requirements. Poor growth and a yellow, chlorotic conditions results.

On the other hand, strongly acid soils may contain injurious concentrations of active manganese compounds. Under such conditions liming is a corrective measure.

Manganese is changed by oxidation to less active forms, or may be leached from the soil. Hence, tests are of most significance when made just prior to planting or during crop growth. A negative test at such time indicates the desirability of applying manganese [1]. Twenty-five pounds of commercial manganese sulfate per acre is usually adequate to correct any possible deficiency. Soluble manganese occurs under conditions of poor aeration and drainage and may be present in toxic amounts for some plants.

It is doubtful that manganese is needed if any positive test whatsoever is developed. Medium or moderately low tests are of little significance [1], except as indicating no manganese deficiency. High or very high tests are undesirable on all acid soils, and indicate a need for lime. It is very unusual to find high tests on soils which are neutral or alkaline. However, it is not likely that the crop will develop manganese toxicity, except at the more acid soil reactions, even though the test is high.

Iron Test

Iron is an abundant constituent of all soils, existing in the form of iron oxides and many complex mineral combinations. Normally only very small amounts of iron are in an active form in the ferric state of oxidation. Under conditions of high acidity larger amounts are found, and under poor drainage conditions, especially in the presence of organic matter, active ferrous iron compounds are developed. Soluble ferrous salts are harmful to plant growth and contribute to the infertility of poorly aerated soils.

The presence of very low, yet definite amounts of active iron, as revealed by the test, is desirable for all crops. Higher amounts, on well drained soils, may not be injurious to crops capable of growing under strongly acid conditions. Abnormally high iron tests on poorly drained soils indicate an unfavorable condition of soil aeration.

Negative iron tests may occasionally result on heavily limed soils of excessive sandiness. In such cases, a chlorotic condition of the leaves may develop, which is controlled by spraying the plants with iron salts. Only one case of this sort has been encountered in this State.

Indication of Other Tests

Occasionally soils which produce poor crops contain unusual or harmful concentrations of other chemical constituents. The presence of sea water or white alkali salts is indicated by chloride, sodium and sulfate tests. Soluble carbonates and high sodium tests indicate black alkali accumulations. High tests for zinc, lead, copper, mercury and arsenic sug-

[1] Not necessarily for tobacco.

gest development of injurious amounts of these elements as a result of soil contamination by industrial plants, or as residues from soil treatments to control plant diseases or insects. The boron test may be applied when crops are suspected of boron deficiency, and if a positive test is not obtained, a more accurate laboratory test for boron may be made. The molybdenum test is the newest addition to the list.

SUMMARY

The soil testing methods developed at this Station during the past 20 years have been built around the employment of a 10 per cent solution of sodium acetate in 3 per cent acetic acid, buffered at pH 4.8, for the soil extraction. This has been designated, for convenience, as the Morgan soil extracting solution. This scheme of testing, identified as the Morgan Soil Testing System, has been found to be of great value in chemical soil diagnosis, not only in this State, but in many sections of the United States as well as numerous foreign countries.

The revised methods used in these tests are presented in detail. Routine tests, of general application, are as follows: nitrate and ammonia nitrogen, phosphorus, potassium, calcium, magnesium, aluminum and manganese. Special tests provide indications relative to the following constituents: iron (both ferric and ferrous), sulfates, nitrites, sodium, chlorides, carbonates, boron, zinc, copper, mercury, lead, arsenic and molybdenum.

The adaptations of the tests to plant tissue testing, the examination of drainage and irrigation waters and other dilute aqueous solutions, and the testing of saline and alkali soils are also presented.

Considerations involved in the practical interpretation of the tests under various conditions are discussed at length.

Details of pH testing are also included. The significance of soil reaction with respect to lime requirement, and the interpretation of quick chemical tests is given due attention.

The modifying effects of physical soil properties and other factors limiting crop growth are also stressed.

Methods such as these described in this bulletin are capable of yielding valuable information concerning the chemical characteristics of the soil and are extremely helpful when interpreted by an individual competent to offer sound advice in soil management practices.

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APPENDIX

Procedures in Brief for the Principal Tests

For handy reference after the technics described in the text have been mastered.

REACTION

(pH meter) 20-40 ml soil; add water to make thin paste.
(colorimetric)
½ tsp soil in test tube; add barium sulfate, 4 ml water and 3 drops of indicator.

EXTRACTION OF SOIL

1 tsp sieved soil
10 ml extracting solution (for alternate procedures see text)

NITRATE NITROGEN

3 drops extract
2 drops brucine solution
7 drops sulfuric acid
Read after 15 minutes.

or

1 drop extract
4 drops diphenylamine-sulfuric acid
Read after 2 minutes.

AMMONIA NITROGEN

4 drops extract
2 drops Nessler's reagent
Read after 1 minute.

PHOSPHORUS

10 drops extract
1 drop phosphorus reagent A
2 drops phosphorus reagent B
Read after 1 minute.

POTASSIUM

10 drops extract
1 drop potassium reagent A
10 drops potassium reagent B
Let stand 1 minute before shaking.
Read after 2 minutes.

CALCIUM

10 drops extract
1 drop calcium reagent
Read after 5 minutes.

MAGNESIUM

10 drops extract
1 drop magnesium reagent A
3 drops magnesium reagent B
Read after 1 minute.

ALUMINUM

2 drops extract
2 drops extracting solution
1 drop aluminum reagent
Read after 1 minute.
1 drop stain remover

MANGANESE

10 drops extract
2 drops manganese reagent A
1 drop manganese reagent B
Read immediately, one test at a time.

FERROUS AND FERRIC IRON

10 drops extract
3 drops iron reagent A
1 drop iron reagent B
Read after 2 minutes.

FERRIC IRON

10 drops extract
3 drops iron reagent A
1 drop iron reagent C
Read after 2 minutes.

FERROUS IRON

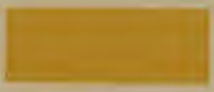
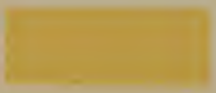
10 drops extract
2 drops iron reagent A
1 drop iron reagent D
Read after 2 minutes.

APPENDIX

PLATE I.

NITRATE NITROGEN COLOR CHART

Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	25	8	
Medium High	12	6	
Medium	6	4	
Low	3	2	

* Test made on 3 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

ERRATUM

Bulletin 541

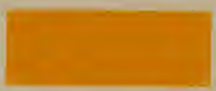
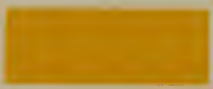
The Morgan Soil Testing System

Plate II. Ammonia Nitrogen Color Chart

Medium High Should Be

AMMONIA NITROGEN COLOR CHART

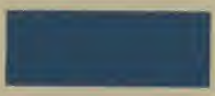
Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	150	8	
Medium High	80	6	
Medium	35	4	
Low	12	2	

* Test made on 4 drops of undiluted extract. If diluted before testing, multiply by appropriate factor.

PHOSPHORUS COLOR CHART

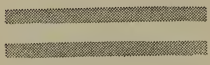
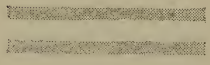
Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	100	8	
Medium High	50	6	
Medium	25	4	
Low	12	2	

* Test made on 10 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

POTASSIUM READING CHART

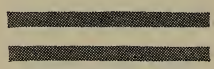
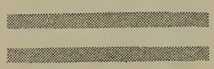
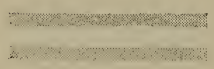
Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	250	8	
Medium High	180	6	
Medium	120	4	
Low	60	2	

* Test made on 10 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

CALCIUM READING CHART

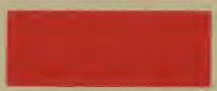
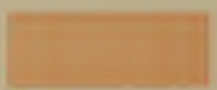
Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	1600	8	
Medium High	1200	6	
Medium	900	4	
Low	500	2	

* Test made on 10 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

MAGNESIUM COLOR CHART

Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	125	8	
Medium High	50	6	
Medium	25	4	
Low	12	2	

* Test made on 10 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

ALUMINUM COLOR CHART

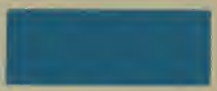
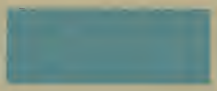
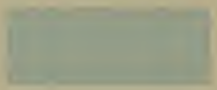
Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	125	8	
Medium High	50	6	
Medium	25	4	
Low	10	2	

* Test made on 2 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

MANGANESE COLOR CHART

Morgan Soil Testing System

RATING	APPROX. PPM IN SOIL *	RELATIVE TEST INDEX	
High	40	8	
Medium High	25	6	
Medium	12	4	
Low	5	2	

* Test made on 10 drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.